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Design Standards for Grade A Plant Producer Farm Dairies — *Gordon L. Nelson*

Application of the Thermocouple in Agricultural Research — *Coby Lorenzen, Jr.*

Some of the Practical Aspects of Controlled Drainage — *R. E. Morris, D. H. Harker*

Tapered Roller Bearing Practice in Farm Machinery Applications — *Geo. W. Curtis*

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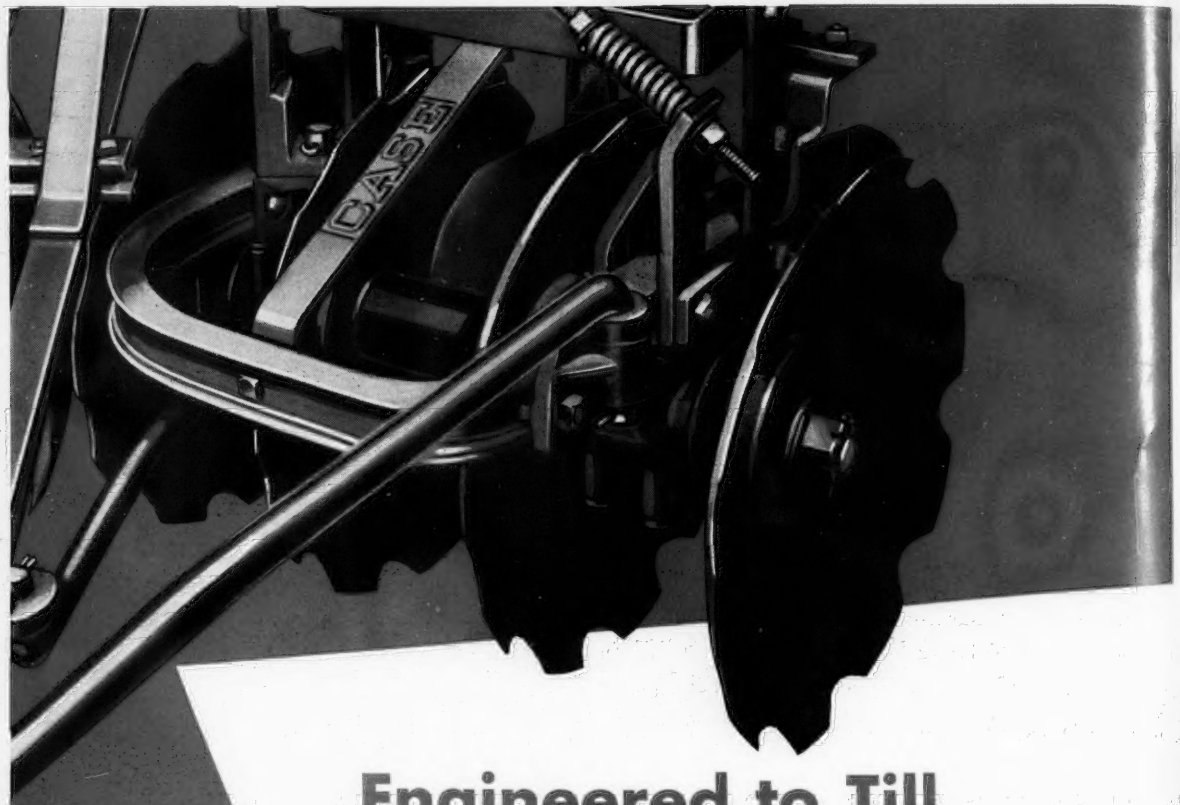

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EDITORIAL

Structures Setup Meets Emergency

THE Midwest Plan Service chalked up a notable victory in May with a high-speed production job of building design and publication. By now, wide circulation has been attained by the 16-page illustrated plan catalog of crop-storage and grain-conditioning structures. Corn crib, grain bin, and farm elevator plans—30 of them—were redrawn, largely redesigned, and reproduced in quantity.

Scarcely more than a month after the planning "task force" met at Iowa State College, to deal with ways and means of meeting the urgent need for new designs, the plan book was on the presses and new tracings were ready for printing. This speed was made possible only by the full cooperation of the Production and Marketing Administration and the division of farm structures and rural housing of the U. S. Department of Agriculture, the agricultural experiment stations in the North Central Region, several trade and industrial organizations, and the Midwest Plan Service.

Regardless of the value of the cooperative effort, however, it would have been impossible to handle this job except for the groundwork and resources developed over nearly a quarter of a century. Four factors contribute in a major way to this particular planning service: (1) The old Midwest Plan Service, a purely voluntary self-supporting plan service, undertaken nearly 20 years ago, and which is now an official activity in the North Central experiment stations; (2) the North Central Farm Structures Co-ordinating Committee, which was initiated in 1944 by the colleges and the U. S. Department of Agriculture, and which has been further stimulated by the Research and Marketing Act; (3) research extending over a long period of time and including structural design, analysis, field studies of crop storage problems, and fundamental and applied research on crop conditioning, and (4) the continuing efforts of agricultural engineers in farm structures to initiate, maintain, and improve planning services, research, and extension work in this field.

Many individuals in state, federal, and private service have contributed to these programs. Space is not available to list them here, but it does seem appropriate to give a special measure of credit to Henry Giese. Without his patient, persistent, and sometimes stubborn efforts to establish and build the Midwest Plan Service, it would have been impossible to meet the present crop-storage planning emergency. Indeed, the whole regional planning activity owes much to Mr. Giese's devotion to the program.

The original Midwest (Farm Building) Plan Service was initiated by agricultural engineers of the North Central region, working through and under the sponsorship of the Farm Structures Division of the American Society of Agricultural Engineers.

DEANE G. CARTER

Opportunities for Agricultural Engineers

JUNE is a time for reconsidering where and how all of the hopeful young graduates may get started in useful and satisfying careers. The prospects for graduating agricultural engineers appear to be about as follows.

About 100 vacancies in established beginning agricultural engineering positions can be expected to develop this year, by reason of professional advancement, promotions, transfers, and other changes among the graduates of the past year or so. This estimated replacement demand is based on the present ASAE membership of less than 3000, representing a large proportion of present agricultural engineers, and an estimated average active career length of 30 years, or 3 to 4 per cent of new manpower required each year to maintain present numbers in this field. An undetermined additional number will find opportunity in new positions developing with the expansion of present agricultural engineering work in established public agencies and private enterprises.

Further opportunities depend on the establishment of new jobs for agricultural engineers, in new organizations, and in established enterprises where there are none at present.

Considering the wide variety of organizations and positions in which agricultural engineers have proven their worth over a period of years, the numbers of similar organizations which are not yet employing any agricultural engineers represent a visible potential of several thousand job opportunities.

The full development of agricultural engineering, and its possible value to agriculture and related industries, cannot begin to be realized until these potential positions can be created and filled.

Some of these potential employers may be sold on the value of hiring agricultural engineers, by the recent graduates themselves. More can be sold by the influence of established agricultural engineers. In the future it may be desirable to give more attention to cultivating these opportunities at about the rate that graduates and experienced men become available to provide the added professional service.

Engineering Farm Work Functions

A LOT of good skull practice is being applied to farm work simplification or methods engineering, with constructive results in terms of improved equipment and structures, labor saving, quantity and quality of production per farmer, and increased satisfactions in farming as a career.

As a result, it has become quite generally recognized that ton-mile movements and some smaller jobs must be mechanized. What are some further opportunities for the application of engineering principles directly to farm practice, as well as to the improvement of materials and equipment for use on farms?

It occurs to us that any of the following conditions might spark the imagination of agricultural engineers as open invitations to progress:

Any job which requires the human body to exert a force of more than 50-lb, even occasionally.

Any job which requires the human body to exert a force of more than one pound, frequently or repeatedly.

Any work setup in which steps are necessary to move material, follow the work, or reach controls.

Any work setup which requires the worker to operate in an awkward or unsafe position.

Any work routing which requires unproductive backtracking.

Any machine which requires continuous hand feeding or manual attention to its output.

Any livestock feeding plan which does not make extensive use of automatic feeders.

Any sequence of routine work which is not being handled on a production line or job-lot basis.

Any building or building group layout which fails to facilitate production line or job-lot methods of operation.

Any unbalanced power and load combinations.

Any suspiciously high hitching, unhitching, work preparation, or emergency repair time.

Any opportunity to increase the output, yield, or quality of product, or the net annual income, safety, or satisfactions of the farm family one dollar's worth by an investment of $5 in buildings, equipment, or land improvement.

Any dollar of direct labor cost which might be avoided by an annual investment cost of 99 cents or less.

Any scale of operations too limited to justify the use of labor-saving equipment and structures already on the market.

Any failure to practice maximum over-all economy of human time, materials, equipment, structures, soils, water, crops, livestock, transportation and other items in the net yield of farm operations.

In addition to providing motors more efficient and powerful than the human mechanism, engineering has demonstrated its capacity to produce detectors more *(Continued on page 310)*

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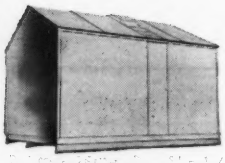

Plans for Grain Bins Utilizing EXTERIOR PLYWOOD

Available from:
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1,000 bu. round bin. Kansas State College design. 14′ diameter, 8′ high. Exterior plywood walls and roof, concrete slab floor. Site construction, using glue. Plan free.

400 bu. movable square bin; several can be grouped. University of California design. 8′x8′ and 8′ high. Exterior plywood walls, roof, floor; lumber frame. Suitable for either prefabrication of site construction. Plan free.

Available from:
Midwest Plan Service, Iowa State College, Ames, Iowa. Or from state college of agriculture at Arkansas, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Wisconsin.

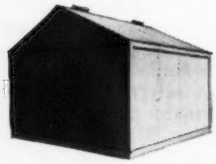
2,000 bu. rectangular bin. Designed for prefabrication. 16′x20′ and 8′ high. Panelized construction permits variety of sizes and capacities up to 3,600 bu. Could be converted to other uses or demounted. Exterior plywood walls, roof, floor; lumber frame. Plan No. 73294. 45 cents.

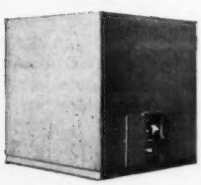
1,400 bu. rectangular bin. 12′x16′ and 8′ high. Other sizes and capacities possible from plan. Bin convertible to other uses. Exterior plywood walls, roof, floor; lumber frame. Site construction. Plan No. 73296. 15 cents.

400 bu. movable hog feeder. Double-purpose storage-hopper. Self-feeding, sloping floor. 8′x12′ and 7′ studs. Exterior plywood walls, roof, floor. Plan No. 77614, 15 cents.

300 bu. movable hog feeder. Double-purpose; provides small storage and sheltered feeder. 10′x16′ with protected feeding floor. Exterior plywood floor, bins, partitions and roof. Plan No. 77613. 15 cents.

Double-farrowing house, convertible to 300 bu. grain bin; 8′x12′; off-center gable roof. Movable. Exterior plywood sides, floor and roof. Plan No. 72626. 15 cents.





GRAIN BINS of Douglas Fir Plywood

will help solve the critical storage problem

AMERICAN FARMERS face a serious shortage of grain storage facilities this year.

According to the U.S. Department of Agriculture, Production and Marketing Administration, present conditions indicate a need for new storage to house over one billion bushels of wheat, corn and other grains. Last year's large crops still fill much of the on-farm and commercial storages — and new facilities must be built to accommodate this year's harvest.

This is not merely a one-year emergency. Large carry-over of grains from one season to the next are expected, and much of this carry-over should be stored in permanent bins built on the farm.

Exterior-type Douglas fir plywood has a proved record for durable, economical grain bin construction. Many sizes and types of bins have been developed and tested by leading agricultural colleges. Hybrid seed corn growers have used plywood construction in their drying bins and elevators for more than ten years.

Primary advantages of plywood for this purpose include:

1 Tight Construction: Plywood bins keep moisture out, resist leakage and spoilage. They provide good insulation because plywood is real wood; the ease with which they can be painted a light color provides additional protection through reflective insulation. Fumigation is easier, more certain.

2 Fast Construction: Large, light, accurately dimensioned plywood panels speed construction for farmers, farm builders and prefabricators. They can be "worked" with ordinary tools, assembled by nailing or gluing. Labor is saved.

3 Vermin-Proof: Tight, smooth plywood walls provide no harbor for weevils or other grain insects. Rats and mice do not find ready access because there are few exposed joints to provide "toothhold."

4 Light, Strong: Plywood's diaphragm action contains grain pressures, adds structural strength, eliminates need for lateral wall bracing. Movable bins are possible because of plywood's lightness and resistance to racking. Bins resist wind damage, full or empty.

5 Adaptable, Attractive: Plywood bins have been designed for all grains. They are often convertible to other farm uses; if desired later the plywood can be salvaged for other buildings. Some are demountable—an advantage to tenant farmers. They finish well, are attractive.

6 Durable: Plywood is real wood—with all of Douglas fir's natural durability. Exterior-type, used for farm purposes, is bonded with completely waterproof phenolic resin adhesive, especially for permanent exposure to weather.

Douglas Fir Plywood

LARGE, LIGHT, STRONG *Real Wood* Panels

Available to agricultural engineers — the following specific data on plywood construction: "Designing with Plywood," "Deflection Charts," "Insulating with Plywood," "Lateral Bearing Strength of Nailed Joints," "Design of Flat Panels with Stressed Covers." Write:

Douglas Fir Plywood Association, Tacoma 2, Washington

AGRICULTURAL ENGINEERING

VOL. 30 JUNE, 1949 NO. 6

Design Standards for Grade A Plant Producer Farm Dairies

By Gordon L. Nelson

MEMBER A.S.A.E.

PLANT producer farm dairies for milking and sanitary handling of raw milk under grade A permits have been built in large numbers throughout the South and Southwest. Fig. 1 shows a typical structure. These grade A barns generally include a milking room with four or more back-out-type stalls, a milk room, and a feed room; and are designed to suit local ordinances modeled after the milk ordinance and code recommended by the U. S. Public Health Service. Cows are milked in groups of four or more, making a barn with only a few stalls satisfactory for large or small herds. If herd shelter is needed, this is provided elsewhere.

Construction of many more of this type grade A barn will be undertaken as expansion of dairying continues; as consumers become educated to demand high sanitary standards for production of milk for butter, cheese, ice cream, and other dairy foods, as well as for whole milk consumption; and as local inspectors become less lenient with producers having inadequate facilities. Uniform design standards agreed upon by sanitation specialists and engineers can help make sure that new construction will be economical and well planned for cleanliness and efficiency in producing milk. Standardization in design and construction is quite feasible for grade A milking barns because the operations are all of a fixed and routine nature, and one size building will accommodate large or small herds.

Grade A dairy barn standards have already been worked out jointly by college and state authorities of four southeastern states, including Virginia, Georgia, North Carolina, and South Carolina, and a retailing organization planning to sponsor construction of grade A barns as part of a merchandising program. Wisconsin, Ohio, Michigan, and New York City milksheds have each published milkhouse design standards cooperatively sponsored by college, state, and municipal groups regulating milk supplies. Other similar undertakings could be cited. In each case, the standards have been published as a model layout to aid in obtaining satisfactory construction of grade A dairy facilities. Dairymen, builders, material dealers, milk inspectors, financing agencies, and agricultural workers in dairy programs all profit from such endeavors. Barns and milkhouses built according to the standard will ordinarily satisfy inspectors in the several markets which a dairyman might use under changing marketing conditions and programs. Builders and material dealers can work out assembly-line construction methods and closely estimated costs when a standardized design can be used for many buildings. A turn-key price can then be quoted to the dairyman who always wants to know "What is the price?" before deciding to build. Economies possible in constructing a number of units according to one design can be passed along to the dairyman. Local dealers have a basis for merchandising a complete building rather than building materials, just as the implement dealer sells a complete machine rather than metal stock and fastenings. Milk inspectors can use design standards in advising prospective grade A producers, and feel confident that their advice accords with approved engineering and sanitation principles. Financing agencies, including milk plants, local banks, or other groups will be encouraged to make loans for construction of grade A barns if standards are available to help make sure that each barn will be a sound investment.

Some considerations leading to design standards developed cooperatively by the agricultural engineering and dairy departments of Oklahoma A. and M. College, Oklahoma State Health Department, and nineteen county and city health departments are presented here. These are largely based on surveys of existing grade A milking barns in Oklahoma and published data. Clifford Gay[1]* has obtained valuable data, cited in several instances following on fly control as influenced by certain design features in 80 grade A farm dairies in Payne County, Oklahoma, during 1947 and 1948.

Arrangement. The building, (Fig. 2) includes a milk room, milking room, and feed room opening into a feed alley ex-

This paper was presented at a meeting of the Southwest Section of the American Society of Agricultural Engineers at Texarkana, Ark., April 15, 1949.

GORDON L. NELSON is associate professor of agricultural engineering, Oklahoma A. and M. College, Stillwater.

* Superscript numbers refer to appended references.

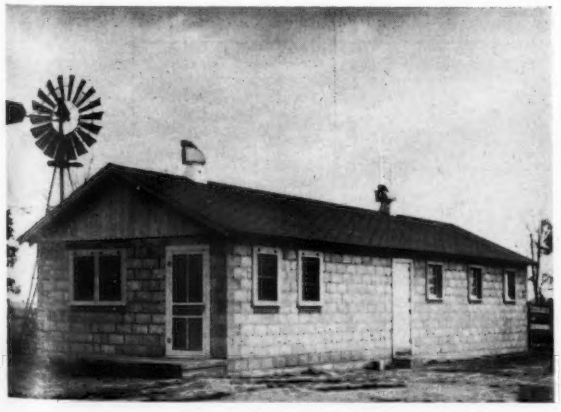


Fig. 1 Grade A milking barns of this type are becoming an important structure on southwestern and southern farms

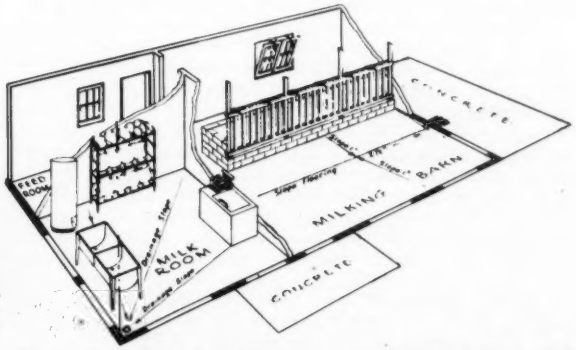
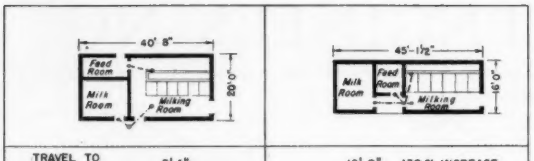


Fig. 2 Clear illustrations help dairymen, milk inspectors, and rural builders understand layout and construction of grade A milking barns



TRAVEL TO FEED ROOM	5' 4"	12' 9" 139 % INCREASE
TRAVEL TO MILK ROOM	9' 10"	11' 9" 19.5% INCREASE
GROSS FLOOR AREA	813.4 Sq.Ft.	732.0 Sq.Ft. 10% DECREASE
TOTAL LINEAR FEET OF WALL	151' 6"	157' 11" 4.2 % INCREASE

Fig. 3 Grade A barns are sometimes built without feed alleys in the milking room, resulting in inconvenience and awkwardness in feeding and milking operations

tending along the front of the mangers. In order to lower construction costs, dairymen sometimes want to reduce barn width by eliminating the feed alley and locating the feed room between the milk room and milking room. The operator places feed in mangers by reaching through the stanchions; and opens or closes each stanchion from a position between the cows. A comparison, as shown in Fig. 3, of two typical arrangements with equal floor area in milk room, feed room, stalls, and litter alley, but with feed alley eliminated in one arrangement, indicates that the price for a floor area reduction of 10.0 per cent through eliminating feed alley is a 4.2 per cent increase in linear feet of wall, a 139 per cent increase in travel to feed room, a 19.5 per cent increase in travel to milk room, and the inconvenience and awkwardness of an arrangement that requires the operator to reach through stanchions to place feed in the mangers and move among the cows to open or close stanchions. The travel distances were figured with reference to the first stall only, and do not include travel to other stalls.

The passageway from milking room to milk room has received considerable attention from sanitation specialists. Health ordinances always prohibit a direct entrance from milking room to milk room. Instead, the milk room and milking room must be separated by an enclosed vestibule or be provided with separate outside entrances to prevent flies from readily entering the milk room from milking room. Doorways in either case must be equipped with outward-swinging, self-closing screen doors. The enclosed vestibule is popular because the operator can travel between milking room and milk room without going outdoors. Gay's summary[1] of his fly counts in milk rooms is shown in Fig. 4. It is clear that an enclosed vestibule connecting milking and milk room gives poor fly control compared to separate outside entrances for milking and milk rooms. Gay did not determine whether or not the human tendency for operators to prop open both doors in the enclosed vestibule at milking time contributed to the results obtained in his study.

Milking Room Capacity. Economy in construction can be obtained by providing the minimum number of stalls consistent with an efficient grain-feeding and milking schedule. Few dairy farms in Oklahoma have stanchions for tying the cows and feeding grain other than in the milking room. If grain feeding is to be controlled so that cows are fed according to production, each cow must have time to eat a measured ration while tied in the milking room. Eating time will vary depending on the characteristics of the cow and amount of grain fed, but dairy specialists say that fifteen minutes is a reasonable allotment. If a two-unit milker is used, and five minutes time is allotted for preparing and milking each pair of cows, a minimum of six stanchions in the milking room are needed. Additional special feeding stanchions in another building would be needed if cows are not allowed enough time in the milking room to eat their full ration.

Milking Room Floor Construction. Milking room floors should be designed for easy cleaning, elimination of tripping

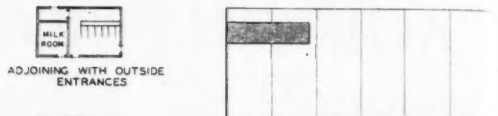


Fig. 4 These data obtained by Gay[1] in 210 separate counts show that separate outside entrances for milking rooms and milk room help keep flies out of the milk room

hazards, and simplicity of construction. A comparison is made in Fig. 5 of three types of milking room floor shown in cross section. On the basis of this comparison, a floor constructed in cross-section shape of a broad flat V as first shown in Fig. 5 without abrupt drops is superior to other styles corresponding to the second or third types. More than three-fourths of grade A barns in Oklahoma have floors constructed with a troughlike gutter or other break in floor level. This does not seem warranted, for each cow spends only a fraction of an hour in the barn, and if correctly managed in the milking room little or no manure is accumulated.

A gritty, non-skid surface over areas of the milking room floor on which cows walk or stand is most necessary. Milking room floors are known to have been so smoothly surfaced that operators could prevent cows from suffering falls only by keeping the floors covered.

Drainage Disposal. Drainage disposal from milking room and milk room is often unsatisfactory in grade A barns because of poor design or unfavorable site conditions. The milk ordinance and code recommended by the U. S. Public Health Service, 1939, requires in section 7, item 6r: "All cow yards shall be graded and drained as well as practicable and kept clean". One of the conditions for satisfactory compliance exists "when the wastes from the barn and milk room are not allowed to pool in the cow yard." Milk and milking room drainage conducted only a few feet beyond the end of the barn usually results in pooling of wastes, manure accumulations, and dirty cow yards unless natural drainage at the site is exceptionally favorable. Gay's studies show that when the cleanliness condition of cow yards was judged in violation of the standard grading ordinance, approximately 17 times as many flies were found in the milking barn and milk house as when the cow yards were judged to be in "good" condition. When the yards were considered to be in "fair" condition, four times as many flies were found as when scored "good". Obviously positive means must be provided for

FLOOR CROSS SECTION	MILKING ROOM CLEANING	TRIPPING HAZARD	FLOOR CONSTRUCTION
	NO GUTTER CORNER TO BE CLEANED	NONE	GUTTER FORM-WORK ELIMINATED, NO CONSTRUCTION JOINT AT GUTTER.
	ONE CORNER AND ONE VERTICAL FACE TO BE CLEANED	ONE STEP UP AT LOCATION OF HEAVY TRAFFIC	GUTTER FORM-WORK SIMPLIFIED, ONE CONSTRUCTION JOINT AT GUTTER.
	TWO CORNERS AND TWO VERTICAL FACES TO BE CLEANED	ONE DEPRESSION TO BE CROSSED AT LOCATION OF HEAVY TRAFFIC	CONSIDERABLE GUTTER FORM-WORK REQUIRED, TWO CONSTRUCTION JOINTS AT GUTTER.

Fig. 5 Milking room floor construction can be improved by eliminating troughlike gutters or other breaks in floor level

conducting wastes beyond the cow yards and lanes. At building sites where the natural slope and location of the cow yard permits, wastes may be conducted away from the barn in a concrete-lined surface drain to a surface outlet well-drained so that pooling is impossible. Such a system is shown in Fig. 6. If natural drainage at the site is poor, a shallow, concrete-lined outside cleanout equipped with cover should be installed to receive wastes from the milking room and discharge liquids into a tile line laid with tight joints and extended to a well-drained surface outlet at a grade of at least ¼ in per ft. The cleanout should be designed for easy cleaning with a shovel, and daily removal of solids should be enforced. Waste from the milk room should be removed by a separate line, and not conducted through the milking room. Mudholes and manure accumulations which serve to attract flies can largely be eliminated by a paved yard where the cows gather before entering the barn.

Manger and Stanchion Construction. Manger formwork can be eliminated and construction simplified by building the front and rear walls of the feed manger using concrete block as suggested in Fig. 7. The manger floor should be constructed at least 12 in higher than the stall platform to permit cows to eat without kneeling or lunging forward while being milked. Where homemade stanchions are used, the horizontal rail anchoring the lower end of the stanchion vertical members to the manger rear wall should be designed so that feed will not accumulate behind or beneath the rail. A suggested detail using angle iron anchors supporting the lower rail with 1½ in clearance is shown in Fig. 7. The manger front wall should be tied to the manger floor with metal ties embedded in the concrete and mortar joint. The manger rear wall should be dowelled to the cow stall floor slab.

Ventilation. Milk rooms are usually ventilated by a vertical flue from an opening in the milk room ceiling to a hood at the roof peak. The milking room, when not ceiled, is ventilated by gable louvers; or if the room is ceiled, by a vertical duct as in the milk room. Data or recommendations are not known that specify the ventilation rate to be provided. The 1939 milk ordinance and code recommended by the U. S. Public Health Service in section 7, item 3r: "Such sections of all dairy barns where cows are kept or milked shall be well ventilated and shall be so arranged as to avoid overcrowding." Section 7, item 8r (c) of the milk ordinance and code states concerning milk room construction: "It shall be well lighted and ventilated." Satisfactory compliance is determined by judgment of the inspector. One state health department recommends that the milking room be ventilated by as many ventilators as necessary, 18 to 24 in in diameter; and that the milk room be ventilated by ceiling type ventilators 12 to 18 in in diameter screened at the top. Before an adequate ventilation system can be designed, the engineer must know the quantity of air removal required under a given set of weather and room air conditions. The A.S.H.V.E. Guide for 1929 recommends that for kitchens and laundries in schools, hotels, and hospitals, from 20 to 60 air changes per hour should be provided. When the milk room is in use, moisture conditions and the need for ventilation are somewhat comparable to those in a kitchen or laundry. A 12-in-diameter flue in a 12x14-ft milk room with an 8-ft ceiling height will provide 6.4 changes per hour; and an 18-in-diameter flue will provide about 14.5 changes per hour with a flue height of 6 ft, an average wind velocity of 5 mph, outside temperature of 25 F, inside temperature of 35 F, and an effectiveness of 40 per cent. (Calderwood and Mack[2] report an average effectiveness of approximately 41 per cent for vertical flue ventilators with plain stationary hoods increasing to approximately 50 per cent for ventilators with rotary siphoning hoods at a wind velocity of 5 mph.) The combined effect of wind velocity and temperature difference are taken into account by the method recommended in the 1948 A.S.H.V.E. Guide. Infiltration and leakage will add approximately 1½ changes per hour making a milk room total ventilation rate of 16 changes per hour obtainable with an 18-in-diameter flue and hood under the conditions specified. Whether or not this rate is adequate is not known, but it approaches the figure of 20 air changes per hour previously cited.

A 24-in-diameter flue or its equivalent in the milking room will remove moisture at the rate produced by 6 cows, assuming the conditions previously specified and an inside air relative humidity of 75 per cent and an outside air relative humidity of 50 per cent.

Screening. Screening against flies is required for all doorway and window openings in the milk room. Outside window screens tacked to the edges of window frames or mounted on removable panels are approved by most ordinances. It has been observed that when screening is tacked to milkhouse window frames, it often tears loose or gaps at the edges. Well-built screens mounted on carefully fitted, removable panels generally remain flyproof and in good repair for a longer period of time and should be recommended. Gay's studies indicate that when milkhouse screens need repair, six to eight times as many flies per milk room can be expected as when the screens are in good repair. Milking room windows should not be screened against flies, but should be equipped with ¼-in hardware cloth as protection against glass breakage and entry of birds.

Delineation. Farmers, milk inspectors, and others not trained in building construction or interpretation of working drawings need pictorial presentation of layout and construction details to help them understand a design. Perspective and cut-away diagrams of the building, as in Fig. 2, are invaluable in meeting this need. Construction details should be completely developed, rather than left to the imagination of the builder. Some builders will not closely follow details, but the conscientious builder will profit by them. Design standards ought to be sufficiently detailed to satisfy the most careful builder, and through constant presentation of details the careless builder may eventually be persuaded to build as shown. If the designer does not feel inclined to prepare complete details, he can hardly blame builders or farmers for inadequate construction.

Design standards should coordinate building materials to eliminate unnecessary cutting and *(Continued on page 274)*

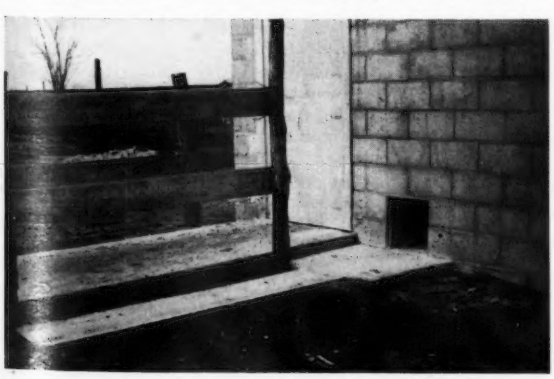


Fig. A well-built, concrete-lined open drain for milking room wastes is satisfactory if liquids are not allowed to pool in the cow yard

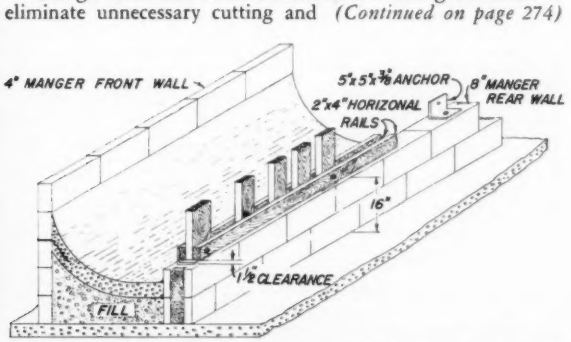


Fig. 7 Manger formwork can be eliminated by building manger walls with concrete masonry units

An Economic Study of Combines

By Kurt Nathan
JUNIOR MEMBER A.S.A.E.

THE importance of the combine harvesting method in New York has increased greatly within recent years. About one half of the grain grown in the state is now combined.

In order to gather information as a basis for a study of the suitability of the various sizes of combines available for different acreages, a survey of 79 machines was made in central New York during 1947. Table 1 presents some of the results obtained in this survey.

Following are some of the additional facts brought out by the survey:

TABLE 1. Some Results of a Survey of 79 Combines in Central New York, 1947

Length of cutter bar, in	40-42	54-60	66-72
Number of combines	13	45	21
Total acres harvested (1947)	50	113	128
Largest acreage of any one small grain crop harvested (1947)	27.0	48.7	61.8
Acres harvested per day	4.8	6.4	7.3
Acres harvested per hour	0.72	1.06	1.19
Hours of farm labor for repair (1947)	6.3	10.8	15.4
Cash expense for repairs (1947), dollars	14.70	24.80	25.20
Cash repair costs per acre (1947), dollars	0.29	0.22	0.19

Barley, beans, buckwheat, clover seed, oats and barley mixture, rye, timothy seed, and wheat were successfully harvested by the combines covered in the survey.

The combines averaged a working day of only six hours because of weather conditions and interference from barn chores.

Owners estimated twelve years as the average expected length of life of a combine.

Over 60 per cent of the operators did custom work.

Utilizing the collected data from the survey, estimates of harvesting costs with the various sizes of combines on different acreages were made. These estimates are graphically presented in Fig. 1. They include depreciation, interest on investment, insurance, taxes, housing, cash repair costs, farm labor for repair, labor for servicing, lubricants, man labor, and tractor costs. It should be noted that they apply to combines equipped with grain bins and power take-off arrangements, and that they do not include the costs of handling the straw and of hauling the grain.

Since for combines equipped with baggers the labor charge for an extra man must be added, the harvesting costs per acre for the smaller sizes of combines would be affected more disadvantageously than the per acre costs for the larger ones because of the greater time involved to harvest any given acreage with a small machine. This relative inefficiency of the small combines is shown in Table 2.

TABLE 2. Days Necessary to Harvest Certain Acreages with Different Size Combines, based on Results of a Combine Survey in Central New York, 1947

Acres	25	50	75	100	150	200
Cutter bar, in	Days necessary to harvest certain acreages					
40-42	6	11	17	23	34	
54-60	4	8	12	16	24	31
66-72	4	7	11	14	21	28

It will be seen from Fig. 1 that small combines (40-42-in cutter bar) operate more cheaply than the other sizes on acreages ranging up to about 35 to 40 acres. The medium size machines (54-60-in cutter bar) are lowest on a per acre cost basis on total yearly acreages from about 35 or 40 to approximately 75 to 80 acres. When this acreage is exceeded, the larger machines (66-72-in cutter bar) harvest more economically.

There seems to be little difference in harvesting costs between the three sizes up to a yearly acreage of 40 to 45 acres, above which the small machines are considerably higher than the larger sizes.

The medium and larger size combines cut at approximately the same per acre cost on acreages between 40 to 45 and 75 to 80 acres. On yearly acreages greater than this, the large machines are a little lower in harvesting costs.

The difference in harvesting costs between the various sizes of combines is due largely to increased labor costs, since the small machines have less capacity and thus the time to cut a given acreage is increased.

Fluctuations in wage rates would affect the estimates considerably, as would changes in machinery costs, since depreciation and interest also constitute a major portion of the total harvesting expenses.

The estimates seem to reveal that in spite of lower initial cost the small combine size (40-42-in cutter bar) is probably impractical even for small acreages, when eventual future needs of a farm business and possible custom work are considered.

This paper was prepared expressly for AGRICULTURAL ENGINEERING.

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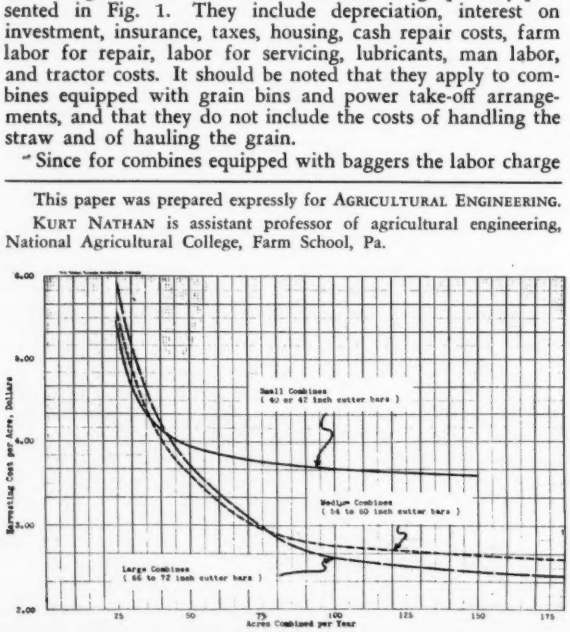

Fig. 1 Estimated harvesting costs under New York conditions, with various sizes of power-take-off-driven combines, equipped with grain bins. (Costs do not include handling straw or hauling grain)

Design Standards for Grade A Plant Producer Farm Dairies

(Continued from page 273)

fitting on the job. Many building material manufacturers are working toward a scheme of modular coordination. Wholesalers and retailers serving the area in which the designs are to be used should be consulted for sizes and types of window sash, doors, and other materials commonly carried in stock, and these should be detailed for minimum cutting and fitting. Otherwise the builder might be placed in a quandary as to how building dimensions and details should be changed to suit available materials. A patched-up construction job can be expected under these circumstances.

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The Thermocouple in Agricultural Research

By Coby Lorenzen, Jr.
MEMBER A.S.A.E.

AGRICULTURAL research embraces a wide range of problems in which temperature is an important variable. Heat balances are performed on plants and animals and on their environments. Storage and processing of agricultural products are critically concerned with temperature. In the field and laboratory, studies may involve transfer of large volumes of fluids with small temperature differences, with the result that heat balances depend upon a high degree of accuracy in temperature determinations.

The thermocouple finds useful application in much of this work. Compared with other temperature-measuring devices it has practical advantages. It is particularly useful in the measurement of temperatures of surfaces, in remote positions, or places where space limitations prohibit the use of any other device.

Accuracy of temperature measurements in any investigation will depend upon the nature of the study. There is no practical gain in determining temperatures to the nearest 0.01 degree when an error of ten times this amount would not appreciably reduce the over-all accuracy of the test. Although this paper is concerned with thermocouple performance, there are instances where the use of simpler devices, such as the mercury thermometer, is entirely justified. It may be mentioned, however, that precautions of calibration, immersion, etc., must be observed if consistent and reliable data are to be expected.

It is not the object of this paper to cover the entire field of temperature measurement by means of thermocouples. This report is concerned with some considerations applying to the use of thermocouples in general, with the construction and application of the butt-welded junction employing wires of very small gage, and with the indication of their possible use from experiences in connection with studies at the experiment station of the University of California at Davis.

When producing a thermoelectric circuit, several factors must be considered. These include the range of temperature to be measured, the thermocouple material, location of the thermocouple junctions, the type of circuit to be employed, calibration, control of the reference junction temperature, and the type of environment, i.e., whether the temperature is independent of or varies with time. Some of these factors are closely related and will be discussed together. For example, the range of temperature is of importance in choosing the thermocouple material.

Although any two dissimilar metals will exhibit a thermal voltage when their junctions are held at different temperatures, relatively few are used extensively for this purpose. The most common of these are copper-constantan, iron-constantan, and chromel-alumel. The thermal emf (electromotive force) of these combinations varies from about 0.020 to 0.030 mv (millivolts) per degree Fahrenheit. The usual lower limit of temperature range for all three types is about 300 F (degrees Fahrenheit), while the upper limits are 600 F for copper-constantan, 1400 F for iron-constantan, and 2200 F for chromel-alumel. A fourth type, platinum-platinum rhodium, of which there are several alloy combinations, generates a slightly lower emf per degree but has a higher upper and lower limit of temperature range, extending from about 0 to 3000 F.

Other combinations of elements and alloys exist which develop two to three times the emf per degree of the couples mentioned above, but their use usually is confined to instruments for the measurement of radiant energy. These include silver-bismuth, (0.042 mv per deg F), and bismuth tin-bismuth, (0.070 mv per deg F).

Location of the junction is an important detail in making temperature measurements. The actual junction must be defined as the line along which the two metals first contact, and the recorded temperature will be that which exists at that point. Assume a junction is formed by twisting and soldering the ends of two wires and the junction is placed in a body so that a portion of the twisted end extends from the surface. If the surroundings are at a lower temperature than that of the body, the recorded temperature will be influenced by the body temperature as well as by the temperature of the surroundings and will be between these two.

Surface temperatures are sometimes measured by touch thermocouples. Experience indicates that this method is useful only when considerable error is allowable. The recorded temperature will be a function of the condition or type of the surface, and the pressure with which the junction is applied. Temperatures of black sheet metal surfaces determined by this method showed errors of 10 per cent as compared with measurements indicated by thermocouples brazed and peened into the surface.

Thermocouple installations may be simple or complicated, depending upon the nature of the investigation. In its simplest form the circuit will consist of an indicating junction, a reference junction the temperature of which is known, and an indicating instrument. Here the chances for error are few. Where the circuit includes a large number of indicating junctions, one or more reference junctions, and switching arrangements that allow the use of one recording instrument, care must be taken to prevent or eliminate circuit errors. These may be caused by

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AUTHOR'S NOTE: Data and experiences presented here are assembled from several different investigations by the agricultural engineering division, University of California. The author wishes to thank the members concerned for illustrative material taken from their work.

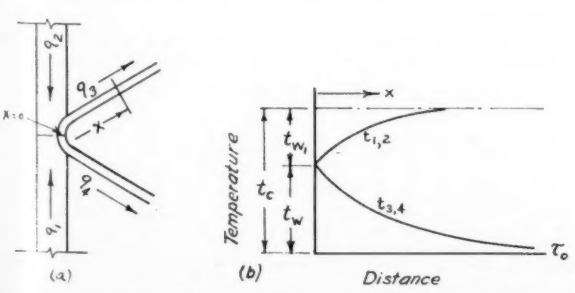

Fig. 1 (a) This shows the thermocouple junction applied at the section x = O. (b) This graph illustrates the equilibrium condition

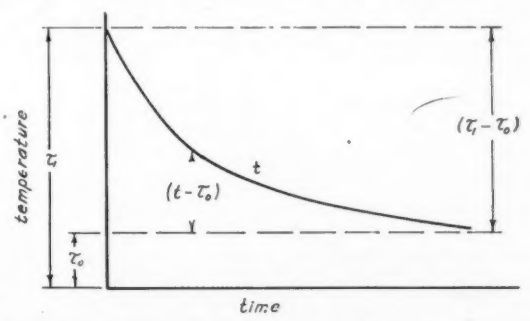

Fig. 2 This graph represents the transient period following a sudden change in the temperature of the surroundings

failure to isolate reference junctions where several such junctions are common to a single reference bath, to stray currents present in parts of the circuit, or to incorrect polarity when couples are connected in series or parallel.

Connecting junctions in parallel in order to determine the average of several points has no particular advantage other than the saving of thermocouple wire and the fact that only one reading is necessary. The separate circuits should have the same resistance and of course must be connected with the proper polarity. The main disadvantages are the possibility of one or more of the couples giving an erroneous indication without detection and the inflexibility of the arrangement. If a separate reading is taken at each point, the average may still be found, as well as the distribution of temperature over the points being studied.

Circuits of multiple junctions with a common return are recommended only where extreme care is taken in their construction and where there is no possibility of stray currents. A short circut occurring between a thermocouple lead and the common return will develop an emf which will cause current to flow in the closed circuit. This will result in all the couples indicating an error. Leakages in this type of circuit, originating for example from electrically driven or electronic recorders, also may affect all the thermocouples in the circuit. If all the couples are in error by the same amount, this trouble is difficult to detect.

In circuits employing multiple junctions located at considerable distance from the recording station, total lead length may be reduced by use of a central reference box, remote switch control, and single leads to the recording instrument. A second, single thermocouple circuit comprising ice bath and with the remote junction in the reference box completes the installation. The requirement for correct indication by all the thermocouples is that all points of the reference box be at the same temperature.

Control of the cold or reference junction of the thermocouple circuit is of course essential in making accurate temperature measurements. The bath of ice in equilibrium with water is the common cold junction used, and is satisfactory when necessary precautions are taken. The bath should be maintained in a thermally insulated container. Distilled water should be used to make the ice, especially when more than one junction is placed in the same bath. It is well to insulate the junctions electrically but not thermally from one to another. This may be done by coating each junction with bakelite enamel or similar material.

Thermal gradients may be present in any liquid bath used as a reference, especially if the bath is large. Stirring liquids or liquid and ice mixtures will tend to maintain the entire bath at a constant temperature. Circulation should be at a very low rate to prevent the energy of the stirring device from raising the bath temperature.

Thermocouples should always be calibrated before being used. If possible, the calibration should be made under the actual conditions of use. Two methods of calibration usually employed are the comparison through a range of temperatures with a standard thermometer, and the establishments of fixed points (melting, freezing, and boiling points) in the range of temperatures in which the thermocouple is to be used. Where extreme accuracy is desired these fixed-point calibration temperatures must be corrected to standard atmospheric pressure.

Aside from the voltage errors mentioned above originating in the thermocouple circuit, thermal errors may occur at the hot or indicating junction. Knowledge of the physical properties of the thermocouple and the kind of application permits calculation of corrections to the recorded data. Four of these seem worthy of some discussion; a more detailed treatment of the subject may be found in the literature cited[2]*:

1 *Heat conduction along thermocouple leads under the condition of unidimensional heat flow and temperature of the surroundings independent of time.* This type of correction is applicable in the case of temperature measurement of parts of plants such as twigs or stems. Assume the temperature of a stem, for example, is uniform along its length; i.e., no heat flow occurs across any section perpendicular to its axis. A thermocouple junction is applied at any section x = o in Fig. 1(a). If the surroundings are at a lower temperature than the plant, heat will be conducted away from the stem by the thermocouple leads and temperature gradients will be created along the stem toward the junction. The equilibrium condition is illustrated in Fig. 1(b), the curves indicating the temperature distributions along the stem and thermocouple wires. Since the small wire approximates the infinitely long rod, the temperature curve for the thermocouple may be represented by the expression

$$t = t_w e^{-\sqrt{\frac{hP}{kA}} \cdot x} \qquad [1]$$

where t = temperature of the wire at any distance from the junction, deg F

t_w = temperature of the wire at $x = o$, deg F

h = unit film conductance between the wire and the surroundings, Btu/ft² hr deg F

P = perimeter of the wire, ft

k = thermal conductivity of the wire, Btu/ft² hr deg F/ft

A = cross sectional area of the wire, ft²

By Fourier's law of conduction, the heat flow across any section of the stem or wire is $q = -kA\left(\frac{dt}{dx}\right)$ [2]

where q = rate of heat flow, Btu/hr

dt/dx = temperature gradient at the section under discussion.

At the section $x = o$, a heat balance may be expressed by

$$q_1 + q_2 = q_3 + q_4 \qquad [3]$$

Differentiating equation [1] and substituting $x = o$ gives

$$\left(\frac{dt}{dx}\right)_{x=o} = \left[-\sqrt{\frac{hP}{kA}} \cdot t_w e^{-\sqrt{\frac{hP}{kA}} \cdot x}\right]_{x=o} = -\sqrt{\frac{hP}{kA}} \cdot t_w \qquad [4]$$

Substituting this result in [2], the heat flow rate is

$$q = -k\left[-\sqrt{\frac{hP}{kA}} t_w\right] A = \sqrt{hPkA} \cdot t_w \qquad [5]$$

It may be noted the temperature along the stem is also expressed by equation [1] when the properties of the stem are used in the constant.

Referring to Fig. 1(a), $q_1 = q_2$, so that the total heat flow along the stem is

* Superscript numbers refer to appended references.

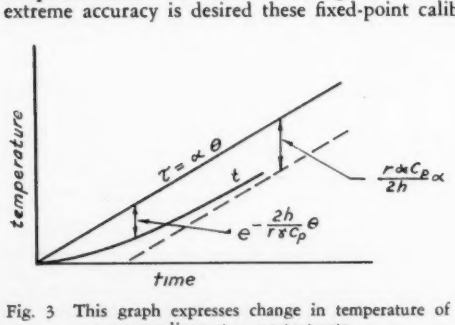

Fig. 3 This graph expresses change in temperature of surroundings at a constant rate

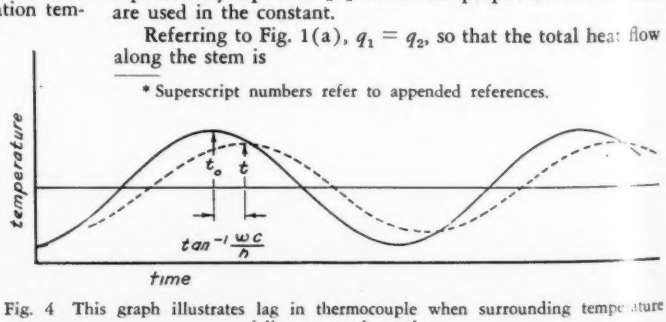

Fig. 4 This graph illustrates lag in thermocouple when surrounding temperature follows a regular cycle

$$q = 2\left(\sqrt{hPkA}\right)_1 \cdot t_w = \left[\left(\sqrt{hPkA}\right)_3 + \left(\sqrt{hPkA}\right)_4\right] t_w \quad \text{[6]}$$

t_c is the original equilibrium temperature of the stem and t_{w1} the drop in temperature due to the presence of the thermocouple, so that $t_{w1} = t_c - t_w$ and

$$t_{w_1} = \frac{\left(\sqrt{hPkA}\right)_3 + \left(\sqrt{hPkA}\right)_4}{2\left(\sqrt{hPkA}\right)_1} \cdot t_w \quad \text{[7]}$$

2 *Conduction of heat in the thermocouple wire during a change in the temperature of the surroundings.* Fig. 2 represents the transient period during which the thermocouple is in surroundings which suddenly change from a temperature τ_1 to a lower temperature τ_o. This transient condition is treated as follows:

The assumption here is that the thermal conductivity is infinite, an approximation which is justified for bodies, such as small wires, where the ratio of surface to volume is large.

The heat change per foot of thermocouple wire per hour is

$$\pi r^2 \gamma c_p \left(\frac{dt}{d\theta}\right) \quad \text{[8]}$$

where r = radius of wire, ft
γ = density of wire, lb/ft³
C_p = specific heat of wire, Btu/deg F lb
t = temperature of wire, deg F
θ = time, hr.

This is equal to the heat transfer to or from the surroundings, that,

$$h\, 2\pi r \left(t - \tau_o\right) \quad \text{[9]}$$

τ_o Final temperature of the surroundings, deg F
h Unit film conductance Btu/ft²hr

Equating these expressions,

$$\pi r^2 \gamma c_p \left(\frac{dt}{d\theta}\right) = h 2\pi r \left(t - \tau_o\right) \quad \text{[10]}$$

or $$\frac{1}{(t - \tau_o)}\, dt = \frac{2h}{r\gamma c_p}\, d\theta \quad \text{[11]}$$

The limits of integration are $t = \tau_1$ and $t = t$,
$\theta = 0$ and $\theta = \theta$

Thus, $$\int_{\tau_1}^{t} \frac{dt}{(t - \tau_o)} = \frac{2h}{r\gamma c_p} \int_0^{\theta} d\theta \quad \text{[12]}$$

$$-ln\left(t - \tau_o\right)_{\tau_1}^{t} = -ln\,\frac{(t - \tau_o)}{(t_1 - \tau_o)} = \frac{2h}{r\gamma c_p}\,\theta$$

or $$(t - \tau_o) = (\tau_1 - \tau_o)\, e^{-\frac{2h}{r\gamma c_p}\theta} \quad \text{[13]}$$

The quantity $(t - \tau_o)$ is the deviation of the recorded temperature from the final temperature at any time θ, so that the time required to approach τ_o within any practical limit may be calculated.

This expression is useful in another form. Leaving it in terms of the logarithm of the temperature ratio and solving for h,

$$h = \frac{r\gamma c_p}{\theta}\, ln\, \frac{(t - \tau_o)}{(\tau_1 - \tau_o)} \quad \text{[14]}$$

For example, plant leaves have relatively high thermal conductivities and low heat capacities. By recording the temperature history of a leaf suddenly placed in surroundings at a different temperature, it was possible to calculate the film conductance of the leaf.

3 *Lag in thermocouples when the temperature of the surroundings is changing at a constant rate.* Occasionally experiments require the measurement of temperatures by thermocouples where the boundary conditions are a linear function of time. Again, for bodies of infinite thermal conductivity the correction, in this case the temperature lag, may be calculated.

As before, the heat gained by the wire per unit length is equal to the heat lost to the surroundings so that

$$\pi r^2 \gamma c_p \frac{dt}{d\theta} = h 2\pi r \left(\tau - t\right) \quad \text{[15]}$$

from which $$\left(\frac{r\gamma c_p}{2h}\right)\frac{dt}{d\theta} + t - \tau = 0 \quad \text{[16]}$$

If the temperature of the surroundings is changing at a constant rate, it may be expressed as $\tau = \alpha\theta$ This is shown in Fig. 3 by the straight line from the origin, indicating $\tau = o$ (or is at the datum) at time $\theta = o$.

Then $$\frac{dt}{d\theta} + \frac{2h}{r\gamma c_p}\, t - \frac{2h}{r\gamma c_p}\, \alpha\theta = 0 \quad \text{[17]}$$

Integration yields $$t = \alpha\theta - \frac{r\gamma c_p}{2h}\, \alpha + C e^{-\frac{2h}{r\gamma c_p}\theta} \quad \text{[18]}$$

If $t = o$ at time $\theta = o$, which will be the case for proper selection of the datum temperature, then

$$C = \frac{r\gamma c_p}{2h}\, \alpha$$

whence $$t = \alpha\theta - \frac{r\gamma c_p}{2h}\, \alpha\left[1 - e^{-\frac{2h}{r\gamma c_p}\theta}\right] \quad \text{[19]}$$

which is shown by the curved line, Fig. 3.

The coefficient of θ in the exponent of e, equation [19], is a constant. Practically it may be determined experimentally from the condition illustrated in Fig. 2 and indicated by equation [14].

The quantity $(\alpha\theta - t)$ then is the temperature lag of the thermocouple at any time θ. It will be noted that as θ increases the quantity in the bracket approaches unity, so that the lag will have a limiting value of $(r\gamma C_p/2h)\alpha$ as indicated by the vertical distance between the solid and dotted lines in Fig. 3. In a graph of time required to reach 98 per cent of final temperature vs. diameter of thermocouple wire, with velocity as parameter, Bailey[3] shows the effect of wire size on this form of lag for thermocouples in air at velocities from zero to 150 fps.

4 *Lag in thermocouples when the temperature of the surroundings varies according to a periodic function.* Investigations may involve determinations of environmental temperatures which vary in a fixed cycle with time. If this periodic variation follows or closely approximates a sine wave, corrections may be applied to the recorded data to reduce the error of temperature and phase lag. The relation[3], assuming infinite thermal conductivity of the thermocouple wire, is

$$t \quad \frac{1}{\sqrt{1 + \left(\frac{\omega c}{h}\right)^2}}\left[t_o \sin\left(\omega\theta - tan^{-1}\left(\frac{\omega c}{h}\right)\right)\right] \quad \text{[20]}$$

where, in Fig. 4, t_o = amplitude of actual temperature variation, deg F
t = amplitude of measured temperature variation, deg F
h = unit film conductance between the wire and the surroundings, Btu/ft hr deg F
c = heat capacity per unit length of the wire, Btu/deg F ft time, seconds
ω = 2π x frequency of the temperature variation, cycles/second

The quantity $\frac{1}{\sqrt{1 + \left(\frac{\omega c}{h}\right)^2}}$ represents the fraction to which

the original amplitude has been reduced, while the phase lag of the thermocouple indication is equal to an angle

$$\alpha = \tan^{-1}\left(\frac{\omega c}{h}\right)$$

The corrections should be calculated and applied wherever accuracy requires them. Examination of the relations presented in equations [7], [13], [19], and [20], however, reveal that decreasing r and increasing h result in smaller values of correction. Since r will be reduced, and in general h will become greater, as the wire size decreases, there is an advantage (where other factors do not interfere) in the use of thermocouples made of small diameter wire.

Development of a simple method of construction of butt-welded junctions, especially in very small wires where the junction cannot be appreciably larger than the wire itself, has aided greatly in applications where space is of major importance.

Use of electric current in forming the butt weld has been tried with little success. The work was limited to copper constantan thermocouple since it was found that this combination had advantages over others for the studies being made. The electric welds were accomplished by current control through condenser discharges. These welds were strong enough, but resulted in embrittlement of the copper wire adjacent to the weld itself.

The method finally used was to braze the junction by use of silver solder. This bond is formed at about 1100 F and at this temperature there apparently is no change in the material as the junctions are as strong as the separate wires.

No particular difficulty is encountered in forming the butt joint with wire of 26 gage and heavier. For smaller wires, a satisfactory technique has been developed requiring certain tools and equipment, as follows:

1 A pair of small, sharp scissors.

2 An alcohol burner. This should produce a flame only large enough to bring the wire up to a dull red temperature, about 900 F. For size 36 or smaller wire, the flame should not be over ¼ in in height.

3 Silver solder filings. Rod or ribbon solder is filed with a clean, fine file, and the filings collected.

4 Soldering flux. Finely powdered borax is used for this purpose.

5 A clamp for holding the wires while forming the bonded junction. Two strips of 16 gage sheet brass about ⅜ in wide and 2 in long are pinned at one end just tight enough to maintain any angle at which they may be set. At the free ends of the strips holes are drilled and tapped to accommodate small machine screws such as size 2 - 56. A small, flat washer is placed under each screw head to form a clamp for the wire.

6 A jeweler's loupe may prove helpful when working with wire of 36 gage or smaller.

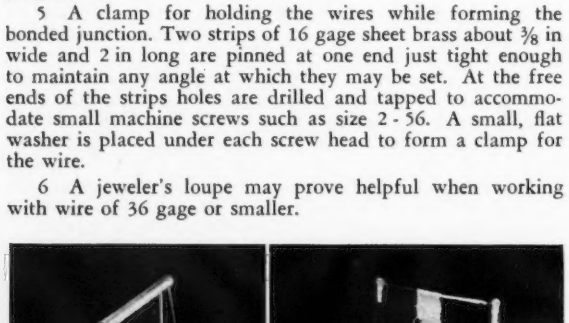

Fig. 5 (*Left*) A junction completely surrounded by a pair of cylindrical shields • Fig. 6 (*Right*) An instrument for accurate determination of humidity and humidity gradients in still air

Proper preparation of the wire ends is important. Cleaning is accomplished by use of fine emery cloth or steel wool and care must be taken to remove all enamel or other insulating material for a distance of ¼ in from the end. The ends should be cut clean and square. The small pair of sharp scissors will shear the smaller wires nicely. For heavier gages the wire may be drawn through a hole of the proper size in a metal block so that its end protrudes slightly, and a very fine file run over the surface of the block. This will form a flat, clean, square face at the end of the wire.

The cleaned wire ends are then tinned. The tip of each wire is moistened, dipped in the borax, and heated above the burner flame to form a bead. This bead should completely cover the tip of the wire. If the bead forms around the wire away from the end, the tip will become oxidized and the silver solder will fail to adhere. Once this condition develops, the best procedure is to cut a short section from the wire and start with a new borax bead. With the bead properly formed, the wire end may be again moistened and dipped in the silver solder filings to collect a very small amount of solder on the surface of the bead. The wire is again heated, this time to a temperature sufficient to melt the borax. At this point the silver solder will flow through the borax and form a thin coating on the wire tip. This operation is performed with both the copper and constantan wires.

The wires are now placed in the clamp, each being held about ¾ in from its tinned end. The clamp is adjusted so that the ends are almost in contact and the wires carefully aligned with one another. The ends are then brought into very light contact and again held in or above the burner flame. Careful heating will bring the temperature of the wires to the melting point of the solder, and the thermal expansion of the metals will cause enough pressure to hold the tips tightly together while the bond is formed. Too much pressure by the clamp before heating will very likely cause the tips to spring past one another and form a lap joint rather than the desired butt junction.

The junctions should be tested before using. This may be done by rolling the wire between two smooth hardwood blocks. Properly formed thermocouples will be found to have the strength of the original wire.

Some experience will be necessary to determine the proper amount of bonding material to give a junction which is not larger than the diameter of the wire. An excess of the material will result in a ball being formed about the junction. Although this may be worked down, it usually is simpler to form a new junction.

The practical use of this type of thermocouple junction and its advantages over other forms may be seen in some of its applications in connection with investigations carried on at the California Agricultural Experiment Station during the last several years.

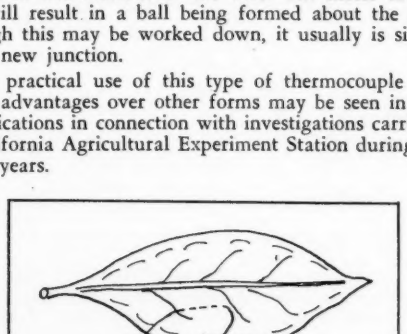

Fig. 7 A thermocouple of very small wire placed directly in the leaf

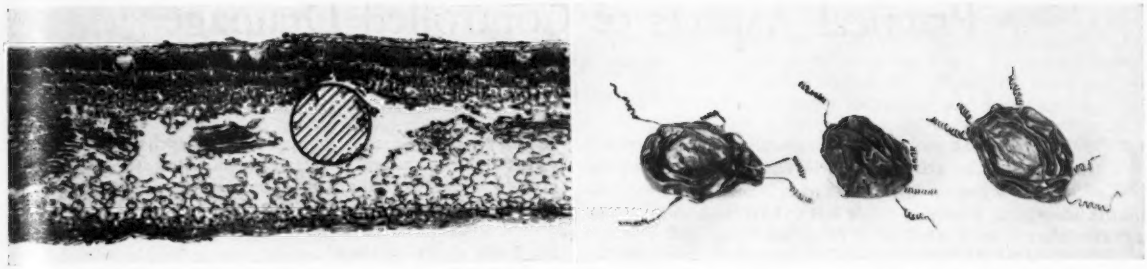

Fig. 8 (*Left*) Photomicrograph of a section of a citrus leaf with the thermocouple in cross section • Fig. 9 (*Right*) Dried prune samples in which thermocouples were threaded before processing

Shielded Thermocouples. Work in orchard heater development involved measurement of temperature of air in the vicinity of experimental heaters where the thermocouple was exposed to the radiation from the heater. Here the indicated temperature of an exposed junction near the heater would be higher than the actual air temperature by the amount of energy absorbed at the junction. A junction completely surrounded by a pair of cylindrical shields, as shown in Fig. 5, reduced the radiant energy error to a small fraction of that allowable.

There appears to be no completely satisfactory analytical treatment of the shielding of thermocouples from errors due to radiation, in still air. Much work has been done, including that of Rohsenow[4] under conditions where gas velocities exceed approximately 10 fps. Observations of Parmelee[5] (without, however, any attempt at mathematical analysis) show that for shields which exceed a limiting value of the ratio of length to diameter, the recorded temperature may be greater than the unshielded couple.

Convection Thermocouples. Orchard heater studies also included determination of temperatures of hot gases flowing through the heater stacks. These gas temperatures in many instances were as high as 1600 F. The heater stack was a sheet metal surface which acted as a good radiator and in environmental temperatures near or below the freezing point high radiation rates resulted in stack temperatures several hundred degrees below those of the stack gases. An exposed thermocouple junction placed in the stack gases would be influenced by the relatively cool walls surrounding it and would indicate too low a gas temperature. The convection thermocouple, a junction placed in a cylindrical tube through which the hot gases are drawn at high velocity, allows accurate measurement of the gas temperature since the thermocouple junction can see little or none of the colder surface.

Examples of use of the very small butt-welded thermocouple include measurement of temperatures of parts of growing plants. In attempting to determine the heat transfer in citrus orchards during frost protection operations, it was desired to find temperatures of oranges at definite points within the fruit. Since temperature data over a period of several weeks was required, it was necessary to maintain the couples without injuring the fruit. This was accomplished by threading couples of 36 gage wire (diameter, 0.006 in) directly through the orange. First applications of this technique resulted in early rotting of the fruit due to bleeding and to bacterial action at the entrance and exit points of the wires. There was also oxidation of the wires due to contact with the fruit juices. When wires were coated with a light layer of bakelite enamel and each entrance and exit point was sealed with a drop of paraffin, no further trouble was encountered. The advantage of this method may be seen in the fact that exact locations of the thermocouple junctions may be found by careful cutting of the fruit at the conclusion of the study.

Thermocouple junctions covered with moistened wicks have long been employed in the measurement of humidity. Devices of this kind with large wires are either restricted to use in air streams where the velocity exceeds the minimum of 10 fps, or must be of the sampling type constituted so that air may be drawn over the moistened junction. There are many instances where either type is unsatisfactory. An instrument developed at the California Experiment Station makes possible the accurate determination of humidity and humidity gradients in still air. Fig. 6 shows one model of this instrument employing single wet and dry junctions of 36 gage wire. Other instruments employ three alternate wet and dry junctions in series. The limiting factors in design of these devices are a total diameter of junction and wick not greater than one millimeter (0.04 in) and a minimum wick length of wet junction covering of ¾ in. Wires of 36 gage or smaller are satisfactory. The wicks usually are cotton threads which have been laundered several times to make them absorbent. The wet junction of the instrument illustrated is covered with a strip of cigarette paper, following the practice of W. V. Hukill of the U. S. Department of Agriculture.

Where the limitation of space dictates the size of the temperate measuring device, the butt-welded thermocouple displays its greatest advantage. This condition may be found in studies involving the determination of leaf temperatures. Here is an example of a body of low heat capacity, the temperature of which may vary through a considerable range in a short period of time. A touch thermopile or similar device would have a sufficient heat capacity to affect the leaf temperature before an accurate indication could be recorded. If the leaf were receiving energy by radiation, it would be difficult to use a device of any appreciable surface area without affecting the irradiation rate and hence the leaf temperature.

Thermocouples of very small wire placed directly in the leaf present a practical solution to the problem. Fig. 7 illustrates this application. A sufficient length of the wire must be contained within the leaf in order that conduction errors will be negligible. For wires of the size indicated the minimum length is 3/16 in. As in the case of the orange, the points at which the wire enters the leaf should be sealed.

The average thickness of the mature orange leaf is 240 microns (0.008 in). Thermocouples of 40 gage wire (0.003 in diameter) may be readily inserted in these leaves. Fig. 8 shows a photomicrograph of a section of a citrus leaf with the thermocouple in cross section.

Fruit and vegetable processing studies are further examples of the use of the fine wire thermocouple. Fig. 9 shows dried prune samples in which thermocouples were threaded before processing.

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Practical Aspects of Controlled Drainage

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CONTROLLED drainage in agriculture is essentially control of the ground-water level by regulation of the flow of water in the drainage system. It is used primarily in organic peat and muck soils. Extensive underdrainage has always been required in these low-lying soils if crops were to be planted, cultivated, and harvested. It has been observed, however, that a drainage system of sufficient capacity to drain the fields adequately in the spring may rob crops of needed water later in the summer. Also, deep drainage has caused these soils to subside or to settle at a very rapid rate.

As a result of these observations, it has become the practice in some areas to drain these soils as completely as possible in the spring and in other wet periods during the growing season and to retard the drainage in dry seasons. In addition to retarding the drainage by means of dams and flood gates some farmers are pumping water from wells or streams into the drainage system to further raise the field water table. This latter practice is actually subirrigation but is included here as a part of the practice of controlled drainage.

Results of Controlled Drainage Experiments in Muck Soils. Since 1942, experiments have been conducted by Purdue University agricultural experiment station and the U. S. Soil Conservation service at Walkerton, Ind. to determine more exactly the benefits of controlled drainage. The crops under investigation are mint, potatoes, onions, sweet corn, cabbage, celery, carrots, and red beets. Of these, mint, potatoes, and onions are raised most extensively on northern Indiana and lower Michigan muck farms at the present time. In so far as crop yields are concerned, those in charge of the experiment can make only a general statement at this time. The data indicate that a water table depth of at least 24 in is required during the major part of the growing season if crop yields and quality are to be adequate. At water table depths less than 2 in yields and quality are greatly reduced. At water table depths greater than 24 in small yield increases are sometimes indicated. Plots having their drainage systems designed so that deep drainage can be effected are more readily planted and cultivated in wet periods.

Subsidence data taken in conjunction with the above experiments indicate 0.4 ft of surface settling during a 3-yr period in two plots which have been drained to an average depth of 40 in. Plots variously drained to average depths of 17 in through 30 in have subsided about 0.15 ft in the same 3-yr period[1]*.

There are at least five main causes of subsidence, and all of them are made more important by increased drainage. The first cause is oxidation of the soil. As the water table is lowered, air penetrates the soil to greater depths, the organic material in the soil, which is its main body, is oxidized and consequently some of the soil solids go into the atmosphere as carbon dioxide.

A second cause of subsidence is the change in the effective unit weight of the soil as the water table is lowered. Soil located below the water table bears downward with a unit force equal to its buoyant unit weight. The buoyant unit weight is the actual unit weight of the soil less the unit weight of water. This same soil when located above the water table bears downward with its actual unit weight. This means that lowering the water table 2 ft will increase the pressure on the layer of soil at the new water surface by 125 lb per sq ft. When the highly compressible nature of peat and muck soils is considered, it can be seen that such an increase in compressing forces is an important cause of subsidence. Other factors are shrinkage caused by excessive dryness, wind erosion, and the compacting action of heavy machinery. During dry seasons large cracks occur in organic soils indicating relatively great shrinkage in the horizontal plane. It is logical to assume that shrinkage also occurs in the vertical direction.

Dry unprotected muck fields "blow" very badly. Severe winds blowing across a one-half mile wide unprotected field will occasionally deposit soil drifts of more than 12 in in height beside a windbreak or in a ditch.

Heavy machinery causes at least temporary and local soil compaction. Probably the soil rebounds from this action to the extent that machinery is not an important factor in causing permanent surface subsidence.

As a part of the muck experiments at Walkerton, subsidence surveys have been made on four commercial fields in northern Indiana. In general, subsidence in these fields has been in the order of 0.2 or 0.3 ft in a 3-yr period[2]. One field

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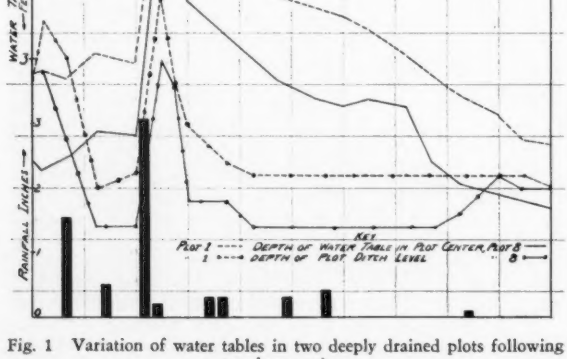

Fig. 1 Variation of water tables in two deeply drained plots following two heavy rains

* Superscript numbers refer to appended references.

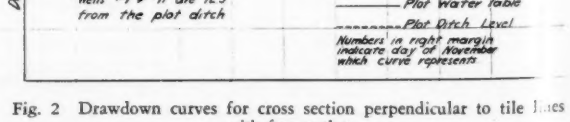

Fig. 2 Drawdown curves for cross section perpendicular to tile lines with free outlets

section of 23 acres had an average subsidence of 0.7 ft with a maximum of 0.9 ft in one small area.

It can readily be seen that subsidence control is itself a sufficient reason for water table control. Most muck deposits in lower Michigan and northern Indiana are not more than 6 ft in thickness. In the light of the subsidence data quoted, it is apparent that conservation measures are required if this valuable soil is to be retained.

Another reason for checking subsidence is the preservation of the drainage system. A system designed for a given elevation of the land becomes less efficient as the land level drops. A tile system placed at an average depth of 3.5 to 4.0 ft on property of the A. M. Todd Company some 25 yr ago is now less than 24 in below the ground surface in most places. The system is now being replaced in order that the field can be adequately drained. New and deeper systems require deeper outlets. In many cases, the outlet streams already have such flat grades that deepening is impossible and pumping plants are required.

Ground Water Movement in Organic Soils. A meager amount of data is available concerning ground-water movement in peat and muck soils. That which is presented here was gathered by the author while working on the aforementioned Soil Conservation Service and the Purdue station project in Indiana. The project layout consists of eight 150-ft by 220-ft plots of about ¾ acre each. Each plot is completely surrounded by an open ditch. The plots and their respective ditches are so arranged and control dams provided so that a different water level can be maintained in each plot. The experiment was designed to study the effect on crops and the soil of maintaining water table depths of 15, 30, and 45 in. Two plots are maintained at each of these levels, and the two remaining plots are designated as variable plots. An attempt is made to furnish water according to the crop's apparent needs on the latter two plots. A sump pump is used to drain the water from the deeper plots and the water thus removed is either diverted into the nearby county drain or is used in maintaining the level of the high water level plots.

Fig. 1 shows the variation of the water table in two of the deeply drained plots during the two heavy rains which followed. In both plots, the rain of July 25 did not appreciably affect the water tables at the plot centers; the 0.5-in rain of July 28 likewise had little effect. Apparently these rains were taken up by the soil as capillary or hygroscopic moisture. The 3.2-in rain of July 29, however, raised the center water table of plot 1 by 1.4 ft and the center water level of plot 8 by 1.7 ft. It then required 21 days to drain the plot centers to their original level. This illustrates that the movement of water through these soils is rather slow.

Fig. 2 shows another drainage experiment in one of the plots which had been tiled. Two lines of tile at a depth of 2.5 ft were installed lengthways in the plots. The tile lines were 50 ft apart and each line is 50 ft from the border ditch.

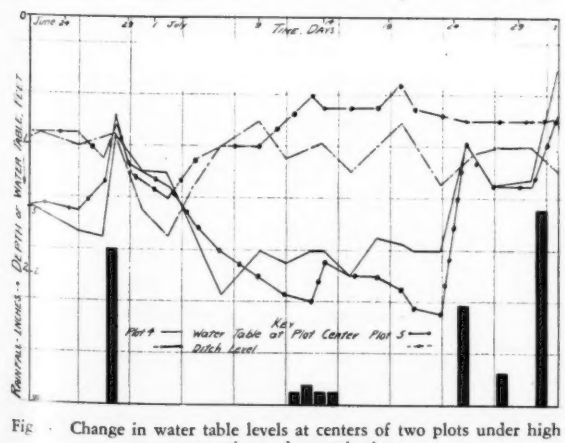

Fig. Change in water table levels at centers of two plots under high evaporation and transpiration

Observation wells were installed at 12.5-ft intervals on a line perpendicular to the tile lines and bisecting the plot. On November 5, the plot ditch water level and the ground-water level stood at 1.1 ft below the surface of the plot. On that day the ditch level was dropped below the tile flow line and the tile thus given free outlets. Readings were then taken to determine the shape of the drawdown curve as the water was drained from the soil. The water table at the midpoint between the tile lines dropped 0.27 ft within 24 hr. On the second day after the experiment was begun, rainfall of ½ in occurred which raised the water table about 0.3 ft. No appreciable rainfall occurred for the duration of the experiment, which ran until November 20. Fig. 2 is a cross section of the plot and the solid lines indicate the shape of the water table on successive days. It can be seen that rapid drainage occurred immediately over the tile lines while thirteen days were required to lower the water table 0.7 ft at the midpoint between the tile lines. This small amount of data is not worthy of exhaustive analysis but is further evidence of the poor drainage characteristics of this soil. Along with the water table curves (Figs. 1 and 2), should be placed the pore space analysis (Table 1) made by the department of agronomy at Purdue University. (Pore space determinations were made under the direction of Dr. Helmut Kohnke of that department.) The percentage of large pores on a volume basis varied from 0.6 to 11.2 in the top 15 in of soil. The large pore spaces are defined as those which will not hold water against the force of gravity. Therefore, if we assume an average pore space value of 5 per cent, it would be sufficiently accurate to say that in order to lower the water table one foot, ½ in of water must be drained from the soil.

In general, crops grown on muck soil will not be injured if the water table can be lowered to at least 6 in below the surface within 24 hr after saturation occurs. Assuming a completely saturated soil at the beginning of such a period and that the minimum drainage requirement has been met at the end of 24 hr, the water table curve at the end of the period could reasonably be expected to appear as shown by the dotted drawdown curve in Fig. 2. The area of cross section above this drawdown curve is approximately 50 sq ft per tile line and would therefore hold about ½ in of water. Therefore, in this tile installation it would be necessary to remove about ½ in of water from the field in order to lower the water table 6 in at the most poorly drained point. Obviously the amount of water which must be removed in order to obtain minimum drainage at the points midway between the laterals will vary with the depth and spacing of tile lines. The drainage modulus for a field must be based upon the drawdown characteristics of the soil as well as rainfall data. The lateral placement will obviously affect the drainage modulus used since this spacing and depth will determine the amount of overdrainage which must be carried out if adequate over-all drainage is to be had. The drainage modulus will govern the design of the mains and submains only.

The second phase of controlled drainage is the application of water to the fields through the drainage system. Fig. 3 shows the movement of the water table at the respective centers of two plots at the Walkerton Station under weather con-

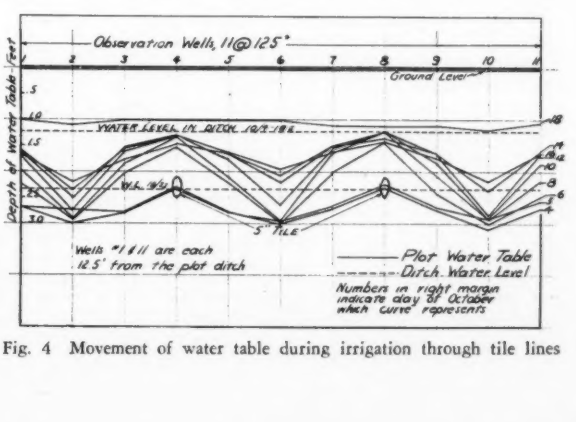
Observation Wells, 11@125'
Ground Level
Depth of Water Table-Feet
5" TILE
Wells #1 & 11 are each 12.5' from the plot ditch
Plot Water Table
Ditch Water Level
Numbers in right margin indicate day of October which curve represents

Fig. 4 Movement of water table during irrigation through tile lines

TABLE 1. PORE SPACE ANALYSIS

Muck Samples from Experimental Drainage Plots Northern Indiana Muck Experiment Farm Walkerton, Ind., 1946

Plot No.	Water table depth, in	Samples taken at 3 in depth (vol. pct. pores by sizes)				Specific gravity, g per cc	Samples taken at 15 in depth (vol. pct. pores by sizes)				Specific gravity, g per cc
		Large	Medium	Small	Total		Large	Medium	Small	Total	
1	40	8.2	4.7	57.1	70.0	1.28	6.3	7.5	67.2	91.0	1.89
8	40	7.5	9.2	45.0	61.7	1.27	11.2	3.2	70.4	84.8	1.44
3	30	10.1	6.3	57.3	73.7	1.39	3.9	2.2	79.9	86.0	1.34
6	30	7.8	8.6	47.8	64.2	1.25	3.9	1.4	77.7	83.0	1.32
4	15	1.9	3.3	62.6	67.8	1.34					
5	15	0.6	1.3	52.1	54.0	1.28					
2	24	3.5	9.5	46.3	59.3	1.31	11.2	11.2	63.7	86.1	1.29
7	24	No samples taken									

ditions conducive to a high rate of evaporation and transpiration in June and July of 1945. A 2.2-in rain on June 28 raised the center water level of both plots to a depth of 0.85 ft. In plot 4 the ditch level was then dropped from 0.9 ft to 1.7 ft and held at that level for four days. Because of the dry atmospheric conditions in the days following the rain, the center level dropped to 1.2 ft within four days and continued to fall to a depth of 2.1 ft at the end of eight days, even though the ditch level was steadily raised to a depth of 0.8 ft. By holding the ditch water level at an average depth of 1.0 ft, an average of 1.9 ft was maintained at the center until rains occurred. Plot 5 followed a similar pattern.

Fig. 4 shows the movement of the water table as water is applied to the plot through the tile lines in the same transverse section shown in Fig. 2. The ditch level was raised from a depth of 2.3 ft to a depth of 1.2 ft and maintained at that level for fourteen days. Twelve days were required to raise the water level 1.0 ft at the point midway between the tile lines. This illustrates the problem faced by farmers who wish to subirrigate in this manner. Unless extremely close tile spacing is employed, it is very difficult to apply water quickly to a field without completely waterlogging the soil immediately over the tile lines. It especially demonstrates the impracticality of attempting to control wind erosion by water table regulation. Crops would be damaged if the permanent water table were held high enough to wet the soil sufficiently to stop wind erosion. A water table held low enough to prevent damage to crops could hardly be raised fast enough to give protection without accurate seven to ten-day forecasting. Cover crops afford a better means of wind erosion control than controlled drainage.

One factor which must always be considered in the design of a controlled drainage system is that of water requirement. No provisions for measuring the amount of water supplied were made in the above cases. However, certain estimates can be made from the pumping station records. In the 1945 experiments, if due allowance is made for water used by other plots, overflow, and seepage losses, it would probably be conservative to estimate that one inch of water per day was being furnished to the plots during the period of greatest evaporation and transpiration loss. This means that as much as 2000 gpm might have to be furnished to a 100-acre field during certain periods of the growing season. As stated earlier, average water tables as high as those maintained in 1945 are considered to be high for good plant growth, but they indicate that maintaining even a 24-in water table may require considerable water.

Controlled Drainage Practice. A typical layout for a controlled drainage system is shown in Fig. 5. The tiling system is designed for good gravity drainage and for holding a relatively high water table when it is required. The line AE is the main line, and the branching lines are the laterals. The contour interval is one foot. Water level control structures are placed in the main line at elevation intervals of one foot. The water level can then be maintained at any desired depth upstream from a given control structure. If an average water table depth of 24 in is desired, the level just above the control structure would need to be at 18 in, assuming a uniform ground slope, and the depth just below the next structure upstream would be 30 in. If this level were being maintained in the section of the main designated as BMC, the depth at M would be somewhat less than 24 in. The depth of N on the lateral MN would then be 36 in. It is evident that a system designed for optimum gravity drainage is not the best system for controlled drainage. For the latter, laterals laid more nearly parallel to the contour lines would function better. However, it would not then be possible to have uniform tile depths and maintain an acceptable drainage grade. In the system shown, if a more uniform depth of water table were essential, control dams would have to be placed in the laterals. It is not common practice to attempt to control the water level to this extent.

Water for such a system would come in part from the field ground water. In dry periods, additional water would be required, and a source located near the higher end of the field would be ideal. If wells were to be used, they should be located near the upstream end of the tile line. Water from streams is often used. Usually a dam must be placed in the stream and the water level built up enough to flow into the upstream end of the system. In other cases, backwater from

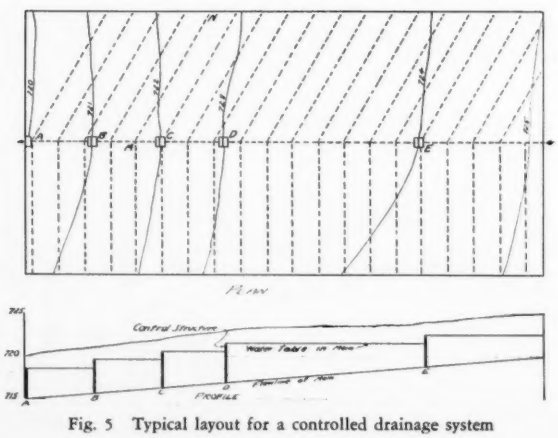

Fig. 5 Typical layout for a controlled drainage system

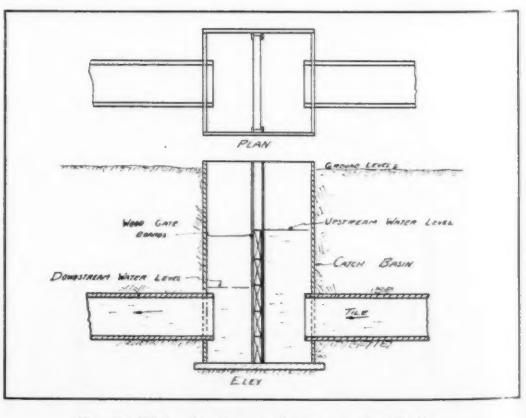

Fig. 6 Water level control structure in tile line

the reservoir can be diverted through ditches to a point where it can be pumped conveniently into the system. Cases can be cited in which pumps were located at each control structure with the main source of water at the outlet end of the system. However, this is not a very satisfactory way of carrying out the work.

Control Structures. The control structures mentioned in the system just described are of simple construction and resemble the one shown in Fig. 6. It is merely a catch basin constructed of wood, steel, or concrete with slides for gate boards in the center section.

Dams for ditch level control may be of many types. The one shown in Fig. 7 is of a type well adapted to the unstable subsoil conditions often encountered in muck regions. It consists of a culvert pipe or pipes laid through an earth dam in the ditch or stream. The total capacity of the culverts with all gates open should equal that of the ditch flowing full. A control box of steel or wood is placed on the upstream end of the culvert tube, and a flood gate is fastened to the downstream end. The box is open on the upstream side and slots or tracks are provided for gate boards, thus allowing for adjustment of the water level. The flood gate is required where there is danger of flooding from backwater or when the ditch is being pumped for drainage. The automatic type of flood gate is preferable. Retaining walls for the dam faces and banks may be constructed of steel or wood sheet piling. Monolithic concrete might be used. However, since sheet piling cutoffs and timber pile supports would probably be required, it seems best to use driven sheeting for the superstructure as well as the footings. Adequate bank protection is especially important where pumps are being used. The high velocities and excessive turbulence caused by pumps in the discharge bay will rapidly undercut any unprotected banks. Also, a floor of heavy rubble may be necessary in the discharge bay to prevent erosion on the bay bottom and subsequent deposits downstream from the dam.

The pump installation shown in Fig. 7 is typical of those used in raising water over earth dams or levees. The pumps used are generally of the axial flow (propeller) type which have high capacity at low heads. In this work, static heads of from 4 to 6 ft are usually encountered. Such pumps require no priming, are simply constructed, will handle muddy water and a certain amount of trash without damage to the pump, and are economical in terms of operation and maintenance. Stationary industrial gasoline engines are generally used for power with a multi-V-belt power transmission system. Farm tractors are sometimes used with flat belt drives.

The pump shown can be installed to pump from the downstream to the upstream side of the dam when irrigation water is required.

SUMMARY

Complete drainage systems such as the one described in the example involve high first costs. A system similar to this installed in 80 acres of muck on a Van Buren County, Michigan, farm cost approximately $11,000 exclusive of pumps and outlet or water supply development. The main tile line is one-half mile in length and there are 40,000 ft of laterals placed at a depth of 4.5 ft and spaced at 80 ft.

The advantages of a drainage system as such are well known to engineers and farmers. The advantages of the sub-irrigation phase of controlled drainage are as follows:

1 Some water can be supplied through any existing gravity drainage system without modifying that system except to add control structures and to obtain a source of water.

2 Supplemental irrigation can be carried on without hindering other field work.

3 Labor and maintenance costs are very low.

The disadvantages of supplemental irrigation through the drainage system are as follows:

1 High first costs are involved in installing a drainage system which would give really satisfactory uniform irrigation to the field.

2 Very large amounts of water are required as compared to sprinkler irrigation.

3 Organic soils produce best when in a slightly acid condition. Many muck fields are underlain with marl and continued upward movement of water through these lime deposits may raise the field pH to the alkaline side.

4 If heavy rains occur while the water table is being held at a high level, fields become muddy and generally unsatisfactory working conditions may prevail.

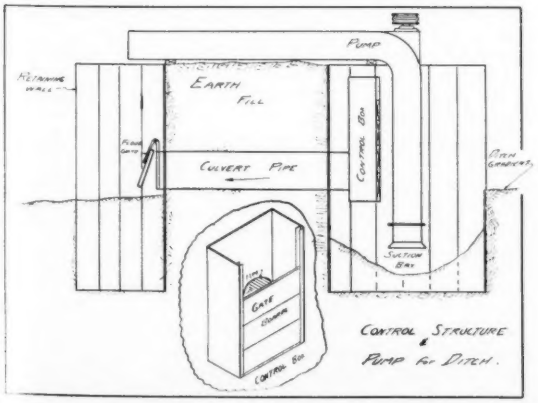

Fig. 7 One type of dam for water level control in ditches

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Discussion by David H. Harker

MEMBER A.S.A.E.

THE principal purpose of controlled drainage, of course, is to provide a means by which free water in the soil can not only be drained out, but also held at certain specific levels through the drier months when the water table would otherwise drop to depths injurious to crops. What the specific optimum depths should be for various crops is not a matter for discussion in this writing. I have found that different growers have different specifications for the depths of water table for various kinds of crops. It is important, of course, to know what crops are to be grown and what depths of control are therefore desirable in each particular drainage case. This can best be determined by a discussion of the matter with the grower himself, using information from the muck crops department in the state university.

Controlled drainage began on muck land and is most likely to continue there for a few years, but eventually it is certain that control will be applied to upland drainage projects. It is only a matter of a few short years until all important artificial drainage will be controlled drainage. It should be now. It should have been long ago. It is a mistake to take free water out of the soil without some provision for coping with perennial midsummer drought conditions. Muck crop farms are simply the guinea pigs upon which the controlled drainage operations are being performed and perfected.

This paper will be directed particularly at the general principles of controlled drainage. First of all, it is important, because of the delicate grading and control necessary, to run all drainage lines with the slope as nearly as possible and

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against the slope only when absolutely necessary. It is frequently necessary to rearrange existing open ditch outlets for the best drainage and control. This means not only straightening crooked marsh runs, but it means also the relocation of open ditches sometimes in order that the water flowing past the farms may be more easily conducted into the upper ends of mains for the purpose of bolstering the water table during the dry months.

Gravity drainage in the open ditches is of course a great advantage economically, and it should be sought as far as is practical. However, if the condition of outlet downstream from the case in point is such that it is doubtful that gravity drainage can be maintained to sufficient depth to provide outlet for the drainage and the control desired, it will then be necessary to deepen the system of open ditches through the farm in question and to provide a dam at the lower end of the farm, over which the water can be pumped when drainage is the need. It is often possible to arrange this dam so that in dry times pumping can be reversed and water can thus be returned to the open ditches on the farm and finally to the tile lines.

In so far as the tile ditches of a controlled system are concerned, it is most important first of all that the tile be adequate for drainage purposes. In case very delicate control is desired, it is necessary to plan the system with tile sizes and grades sufficient to remove the water from the land at the rate of not less than ⅜ in in 24 hr and preferably at the rate of ½ in in 24 hr or even more. Controlled drainage, while it is more detailed, can be responsible for keeping water in the soil and removing it too slowly in case of sudden storm, if all tile lines are not ample in capacity.

If mains are to be used for delivering water for overhead irrigation, it is very likely that even larger diameter tile will be required. Then the controlling factor is not how much rainfall it will be necessary to remove from the land, but what quantities of water will be required for irrigation.

REROUTING NATURAL DRAINAGE SYSTEMS

As was suggested earlier in this discussion, it is advantageous sometimes to reroute the natural drainage streams serving the muck land in question in order to place them where they may, while serving as outlets, also deliver water to the upper ends of tile drainage systems. This is usually possible in part, but it is most often impractical, and often impossible, to supply water to all parts of the tile drainage system by this method. It then becomes desirable to drill wells at the head ends of some of the tile lines in order to provide "make-up" water for the drainage system. This has been done in a number of cases. It is not as expensive as it sounds for the reason that there are only brief periods in the normal year when addition of water from wells will be required, and it is surprising how little water may be needed to keep the water table up, especially if the rainfall throughout the season is about normal.

The laterals in a tile drainage system for control are no less important than the tile mains or the open ditches. Laterals should not be less than 5-in tile and they should be spaced in most cases about 50 ft apart. In one instance, we spaced laterals 25 ft apart and they were all 6-in tile, with great success, of course, but at considerable cost. The owner has since indicated that the 6-in tile were larger than necessary and that a 50-ft spacing probably would do the job well enough. The point about closer spacing is simply that, where great uniformity of water table is desired, closer spacing will be needed to get the job done to the best advantage.

As regards grades for laterals, they should be no flatter than necessary because the water table will be maintained above the grade, regardless of it. It is just as important to have non-silting grades in these tile laterals as elsewhere. In general, the grades should fit the land slopes as nearly as possible, but I would lay no 5-in tile on a grade flatter than 1 in in 100 ft, and I would much prefer 1½ to 2 in.

The controlling factor in regard to the amount of fall would be, of course, the uniformity of the depth of tile desired. It is good policy never to grade any laterals shallower than 42 in, even in uplands. I have recently talked to a number of drainage people who indicate that they are encouraging 48-in depth of drainage in all cases. It is important to have depth of drainage to create the proper root zone for crops. Muck crops do not require as deep a root zone but, rather, require moisture at the roots at higher elevation than other crops. However, many muck farmers now are growing corn as an alternate crop on occasions, and for the best corn production, a 42 to 48-in root zone is imperative. Furthermore, there is no point in laying a tile shallower, except to save cost of trenching and allow shallower structures, because the water table can be held high by control in a system built deep as well as in one built shallow. And, finally, depth of drainage is important on muck lands because mucks are known to subside rapidly and seriously, which, if the tile system is placed at shallow depths to begin with, leaves the tile much too shallow after subsidence.

We make it a practice to place 4 or 5 in of loose straw over all tile before backfilling. This forms a compact straw mat over the tile joints, providing easy access for ground water. In some cases where it is desirable to get surface water down to the tile quickly, we place pervious backfill at intervals — such material as cinders, gravel, or even corn cobs.

ADEQUATE STRUCTURES MUST BE PROVIDED

Finally, a controlled drainage system is without control unless adequate structures are provided. In the open ditches this means dams, for impounding water sometimes and at other times for serving as a bulkhead against water which must be pumped out of the land. Ordinarily, the fill material which can be obtained close by in a muck area is not suitable for an earth dam. It is necessary, therefore, either to bring in clay from some distance or to use some other kind of material. Corrugated sheet steel driven to a depth of 6 to 10 ft is used in many places. Concrete structures are used, but in deep muck must be placed on piles because the weight of the structure will otherwise cause settling. All dams must be provided with adequate outlet facilities in order to insure that overtopping will not result and cause failure. Dams must also be equipped with whatever pumps are necessary to introduce water into the system or eject it therefrom.

If streams are rerouted to bring water to the upper ends of drainage systems, intake bays will be needed. Usually the water can be flowed in by gravity, and should be wherever possible, to avoid the cost of pumping.

Probably the most important structures are the stop wells placed in the tile lines. These are box structures made of concrete or steel in which provision is made, by means of 2-in channel iron, to drop in stop logs for damming up the water above. We have built "through" stop wells which have simply the incoming main and the outgoing main with a stop log section between to create the desired differential in water levels. T stop wells have a submain coming in from the side with provision for separate stop-log control in case it is desirable. Often the stop well is a "cross" stop well, which provides for the outlet and three incoming lines with sets of stop logs which make it possible to maintain the water levels on the incoming main and the two incoming submains, all at different levels if desirable.

There are innovations annually in this matter of controlled drainage. Actually, we have not given the subject serious and widespread study and use until in recent years. The developments in the controlled drainage field are being intensified, and the controlled drainage farmer is becoming a producer and a business man in the full sense of those terms.

A CORRECTION

IN THE title of the lead article in AGRICULTURAL ENGINEERING for May, 1949 (vol. 30, no. 5, page 223), the word "loading", instead of "Unloading", was erroneously used. Title should have read: "Results of Tests on Mechanical Unloading Devices for Chopped Forages."

Tapered Roller Bearing Practice in Current Farm Machinery Applications

By George W. Curtis
MEMBER A.S.A.E.

THE changing requirements of field service during the past three decades with respect to loads, speeds, hours of life, and year-round availability has resulted in the widespread adoption of anti-friction bearings in all types of farm machinery. Some farm machines, such as the plow, harrow, and reaper, originated before the anti-friction bearing. Nevertheless the practice of using anti-friction bearings in the wheels of the plow has become as general as in the newer types of machinery, such as rotary tillers, disk plows, hay rakes, forage harvesters, combines, corn pickers, and the like. Therefore, it is the purpose of this paper to discuss and illustrate particularly the use of tapered roller bearings in such equipment.

The adoption of good anti-friction bearing practice generally results in longer life, lighter weights, higher speeds, freedom from lubrication troubles, and lower maintenance costs. The important rules of good practice may be stated briefly as:

1. Determination of applied loads
2. Determination of required life
3. Selection of correct type and size of bearing
4. Determination of proper lubrication
5. Determination of adequate seals
6. Careful handling of parts, before and during assembly
7. Design of practical applications.

The general rules of good bearing practice are generally covered by the various anti-friction bearing companies in their published handbooks or journals, and with very few exceptions need not be repeated here in detail.

In a paper of this length it seems most important to dwell on actual practice as followed in current use. A few especially important phases of the rules of good practice which should have special emphasis are as follows:

1 and 2 Determination of Applied Loads and Life

Today's economics require that we make a rather close selection of the bearings, and we think the first two of the above rules of good practice may be covered together. Where the average load is materially lower than the maximum, we try to obtain information regarding the amount of time the average load is effective and the amount of time the maximum load is effective and select bearing sizes which provide a total weighted bearing life as required by the total over-all machine life. A formula for this purpose is shown as Fig. 1.

Catalog ratings of different makes of bearings cannot be directly compared until the ratings are converted to a common life basis.

For example, tapered roller bearings are rated on the basis of 3,000 hr B-10 life. That is to say, out of a large group of bearings operating under specific loads and speeds, not over 10 per cent of them will fail before 3,000 hr of service. Ninety per cent will be satisfactory for operation beyond the 3,000 hr period. The life of the average bearing in the group will be approximately five times 3,000, or 15,000 hr. The ratings of some types of bearings are published on the average life basis and the calculated life in these instances should be divided by five for a direct life comparison with those of B-10 rating, according to our experience.

Another variable must also be taken into consideration for direct comparisons. The ratings of bearings as published range for lives of 500 to 5,000 hr. Published data book life factors may be used for direct comparisons. For instance, a tapered bearing having ratings based on a life factor of 1.0 to obtain 3,000 hr of B-10 life have a life factor of 0.583 for 500 hr of B-10 life. Therefore, by dividing the published 3,000-hr rating by 0.583, a 500-hr B-10 rating would be obtained for comparison with those bearings which have published ratings on the 500-hr B-10 basis. Therefore, this 500-hr B-10 rating may be directly compared with that of other types of bearings having ratings established on the 2,500-hr life basis.

3 Selection of Suitable Bearing

A selection of the proper size bearings for farm machinery is concerned with obtaining adequate bearing capacity for the desired life and effective operating speed and load conditions. Tapered roller bearings are made with the so-called standard taper for normal radial load conditions and with several degrees of steeper taper for high axial or thrust-load conditions. Therefore, we select that combination of radial and thrust capacity best suited for the particular conditions involved. We have what is known as a "K" factor which shows the relation of the radial rating of a bearing to the thrust rating. Thus a bearing which has a radial rating 50 per cent higher than its thrust rating will have a K factor of 1.5. A steeper angle bearing with a higher thrust rating will have a lower K factor in proportion to its radial and thrust ratings approaching 1, and in some cases less than 1. Thus the use of the K factor is most important in determining the proper bearing for an application which has a combined radial and thrust load. We therefore provide an equivalent load formula to be used in the selection of the proper type and size bearing and this may be obtained from our published data book.

4 Determination of Proper Lubrication

The majority of tapered roller bearing applications, according to our experience, requires some means of replenishing and replacing the lubricant. The relubrication period depends entirely upon the prevailing operating conditions, such as loads, speeds, hours of service requirement, amount of lubricant contamination, and size of lubricant reservoir. Wheel applications are typical instances where grease lubrication has been satisfactory and where relubrication is provided in some form or other, comparable to an automobile front wheel and for which inspection and relubrication are recommended at regular intervals. Farm machinery wheels used under fairly clean conditions, such as haying equipment, where the implement runs over a mat of grass or vegetation do not need as frequent replacement of the lubricant, as wheels used in rice field applications running in mud and water. But in our experience at sometime or other some means should be provided for relubricating the bearings to insure maximum service therefrom. Many types of farm machinery applications are, however, currently designed with enclosed-unit, running-in-oil constructions comparable to the transmission and rear axle of an automobile. Fluid lubrication in such designs may be provided for upwards of a full season's operation without replacement. This method of enclosing and lubricating bearings, gears, etc., has been increasing in farm machinery for over two decades with outstanding success and has contributed greatly to the elimination of daily maintenance labor which formerly was connected with the operation of farm machinery. This reduction of daily maintenance labor is without doubt one of the most important advances the industry has made and will continue until the operator can take his tractor or corn picker out of the shed and go to work, just as he does with his automobile. This may prove to be one of the greatest advantages of anti-friction bearings.

This paper was presented at the winter meeting of the American Society of Agricultural Engineers at Chicago, Ill., December, 1948, as a contribution of the Power and Machinery Division.

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$$\text{B-10 LIFE} = \frac{3000}{\frac{T_1}{L.F_1^{3.33}} + \frac{T_2}{L.F_2^{3.33}} + \cdots \frac{T_n}{L.F_n^{3.33}}}$$

Fig. 1 Formula for determination of applied loads and life of bearings

5 Determination of Adequate Seal

We believe it advisable generally to consult the seal suppliers about sealing problems. A few general rules, however, may be useful. From the operator's point of view no doubt it would be advisable to provide a type of seal which would eliminate all maintenance on bearings for the life of the equipment, but in most cases this has not been possible. *It must be recognized, however, that in many applications the type of seal used will determine the frequency of relubrication, the type of lubrication required, and to a large extent the life and degree of satisfactory service of the bearing.* For any piece of machinery which works in loose dirt, such as tractors, disk harrows, tillage tools, and the like, the best type of dirt seal obtainable should be used. A farmer is no more enthusiastic about absorbing the costs of replacing expensive parts than other users of machinery where such expense can be prevented. The truck roller application of a track-type tractor provides an illustration where a great deal of progress has been made in recent years toward improving bearing life by the use of improved seals and where as a matter of fact it has become imperative to use the most suitable seal. In other types of service where bearings operate under cleaner conditions, on such machines as combines and balers operating generally over fields covered with a mat of grass or straw, experience indicates a more simplified type of seal may be satisfactory. An effort will be made in this paper to point out the seals regarded as suitable for the particular conditions involved.

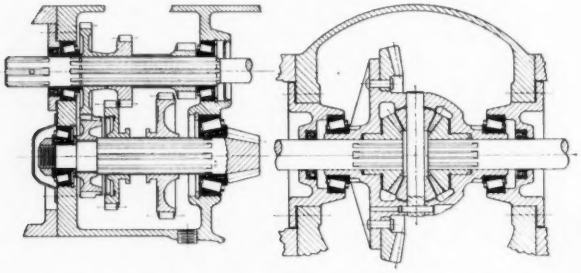

Fig. 2 Transmission and differential of an 18-hp tractor

6 Careful Handling of Bearings

Too much emphasis cannot be placed upon the importance of cleanliness, careful handling, assembling, and lubricating anti-friction bearings. They are manufactured with great care and precision, and every precaution should be taken to install them with the same degree of care as is used in their manufacture. Practices of interdepartmental transportation of loosely packed preassembled shaft units in uncovered containers having exposed bearings, of driving bearings on shafts with hammers, of leaving bins full of bearings uncovered and the like are regarded as very bad. For upwards of a half century we have trained a staff of expert installation engineers for periodic customer plant visits. The primary duty of these installation experts is to promote the use of suitable protective devices, holding racks, bearing containers, pressing fixtures and the like, and we hope this service has greatly aided the general trend toward improved bearing practices. It behooves all of us to exert all our influence continuously toward this end.

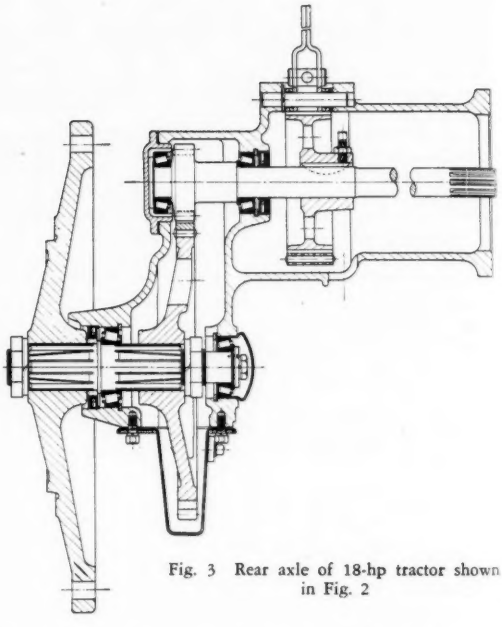

Fig. 3 Rear axle of 18-hp tractor shown in Fig. 2

Farm machines of the forage harvester, combine, hay baler, and corn picker types, are apt to have a multiplicity of bearing applications and subunit assemblies of a similar style and type, thus making undesirable and repetitive a treatment of an entire complement of bearings of any one particular type of machine in a paper of this length. Rather, I believe it was the program committee's desire to have this paper cover the principles of the application of tapered roller bearings to various special shafts and units to bring out the importance of various contributing elements, such as lubrication, sealing devices, adjusting devices, machining requirements, and the like.

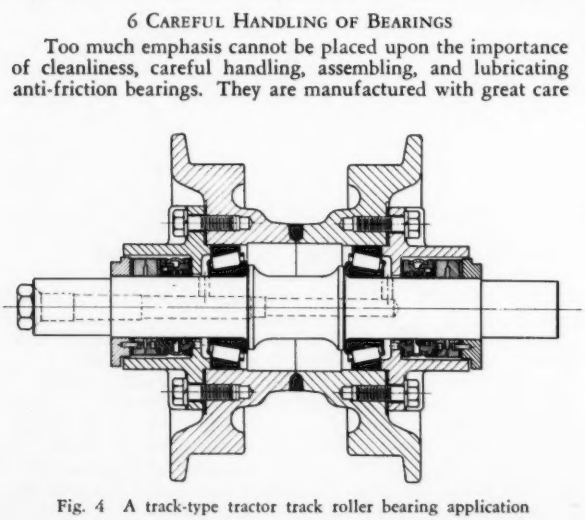

Fig. 4 A track-type tractor track roller bearing application

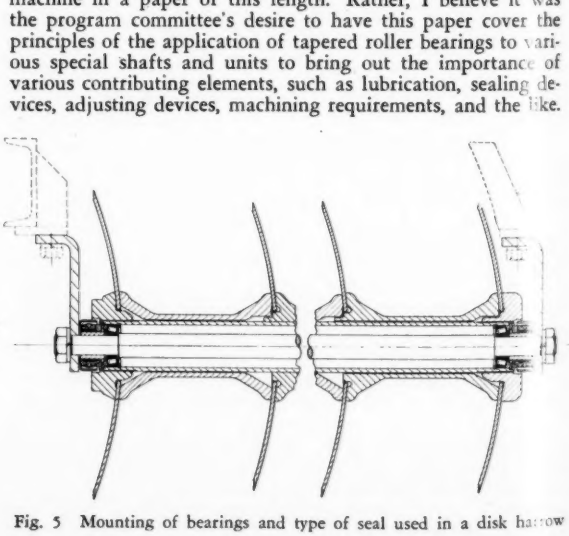

Fig. 5 Mounting of bearings and type of seal used in a disk harrow

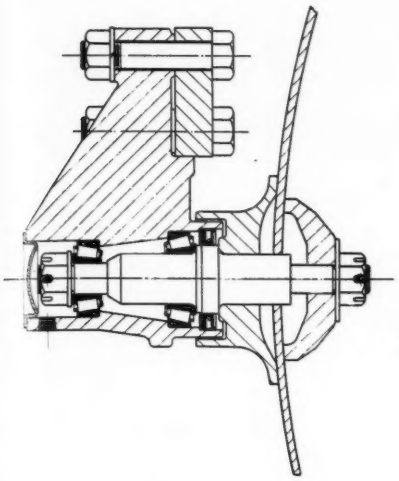

Fig. 6 A concave rolling jointer

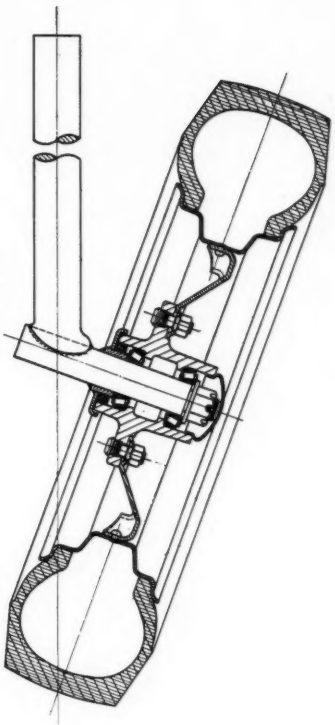

Fig. 7 Mounting of wheel bearings in a one-way disk plow

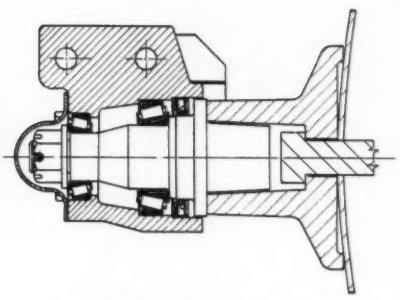

Fig. 8 Section through thrust block of a one-way disk plow

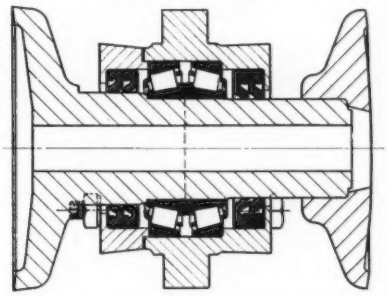

Fig. 9 Application in hanger bearing of one-way disk plow

7 DESIGN OF PRACTICAL APPLICATIONS

The preferences of particular engineering and production facilities generally are most influential in the determination of what each particular organization regards as the most practical and desirable bearing application designs. The precise details of such designs vary widely in different organizations. All, however, place a high value on lowest possible parts costs, tooling costs, machining costs, ease of assembly and disassembly. The importance of this phase of bearing application work cannot be overstated and may be judged by the fact that several of my office's latest proposals have within the past month been the subject of careful time-cost studies by expert time study men. In such organizations new bearing proposals do not get into production unless they compare favorably with old designs. Wide knowledge of what is most practical and satisfactory in bearing applications must come from a study of actual practice.

I am indeed fortunate, therefore, in having the specific permission of more than two dozen different farm machinery plants to review many of their most successful current applications of bearings in such machines as tractors, tillage tools, grain drill equipment, cultivating equipment, hay machinery, grain and corn machinery bearing applications. An effort will be made to point out what is believed to be most interesting about the designs from the standpoint of the engineering and production features.

The formula (Fig. 1) is used for calculating the weighted B-10 bearing life in hours where it is desired to select the bearings for the life of the machine, rather than for the amount of time the bearing may be operated under any one particular load condition. This formula is used, for instance, to calculate life of bearings in a tractor where the tractor may operate in a number of speeds and wherein each speed creates different loads on the bearings. Some tractors have as many as six speeds, and it is only by an accurate weighted-bearing life calculation that a definite machine life value may be obtained for tapered roller bearings. This phase of selecting bearings for tractors was fully treated in a paper presented at the SAE national tractor meeting in September, 1943, at Milwaukee, Wisconsin, by John Borland, and his paper may be obtained from SAE or from my company. The constant 3,000 is used where a life factor of 1 obtains 3000 hr of B-10 life. The T_1, T_2 values are the percentage of time for each load condition and the expression $(L.F.)^{3.33}$ represents the life factor to the 3.33 power. The sum of the T_1, T_2 percentage values must equal 100 per cent.

Tractors. In Fig. 2 is shown a cross section through a transmission and differential of an 18-hp tractor. The notable

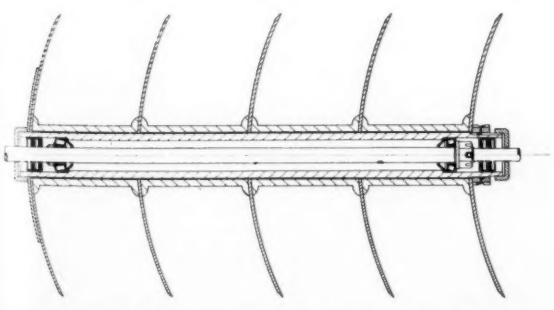

Fig. 10 Mounting construction used in one-way disk plow

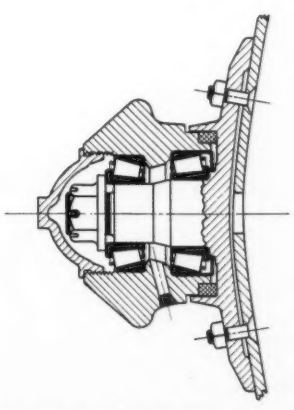

Fig. 11 Disk plow spindle with disk mounted on its own bearings

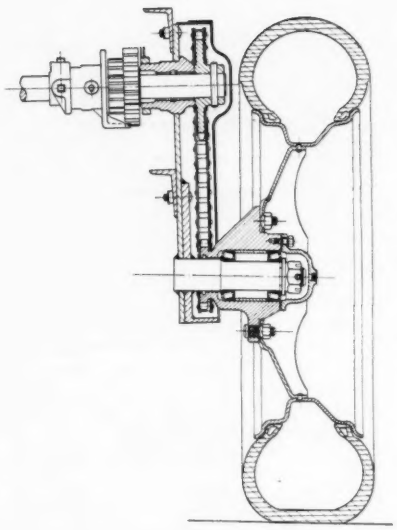

Fig. 12 Application of tapered bearings in a grain drill wheel

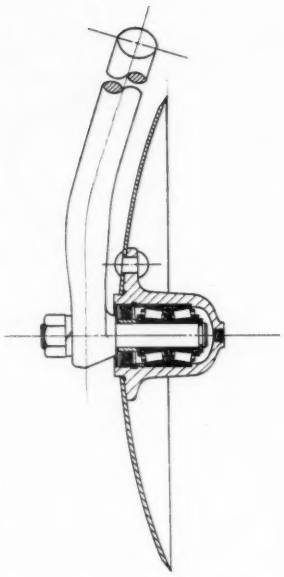

Fig. 13 Bearings application in a disk furrow opener

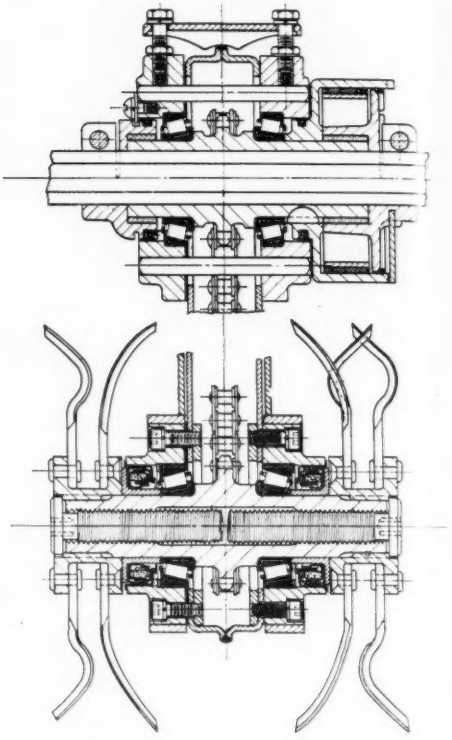

Fig. 14 Tapered bearing applications in a rotating tiller cultivator

features of this design are the fixed or non-adjustable setting of the spiral bevel pinion and gear, the provision for lubricating the bearings, and the rigid construction which reduces shaft deflections to a minimum. I believe this design pioneered the use of the heavy-type snap ring as a means of locating and absorbing the thrust from the bevel pinion bearing, and that after 11 or 12 years' production no question has ever been raised on this feature. The snap ring design simplifies the machining and tooling operation. You who have been part of the farm machinery industry for years may not realize how precision work has been creeping into the production of farm machinery. The fixed bevel pinion setting in this design is a case in point. The location of the snap ring groove used for locating the pinion bearing is held to very close tolerances with relation to the differential cross bore. The pinion shoulder stand and bearing width are also held to precision limits so that no cutting and trying methods are necessary. The installation is made once and must provide proper contact of the spiral bevel gear teeth. There are fourteen different tractor models being built in high production with this type of precision manufacturing standards. During a tour which I made several months ago particularly to investigate the reaction of the various shop organizations to this new type of precision manufacturing requirement, I did not find a single plant reporting difficulty.

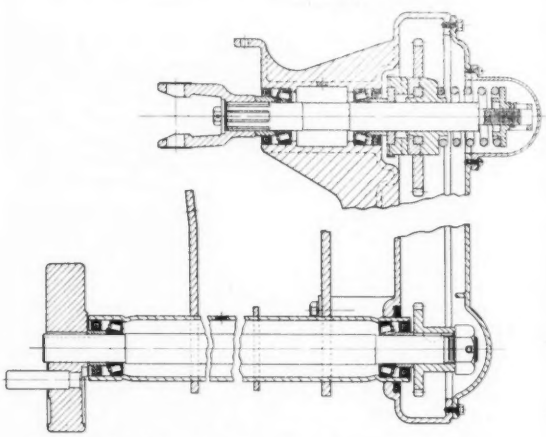

Fig. 15 The drive and pitman shaft of a tractor-powered mow

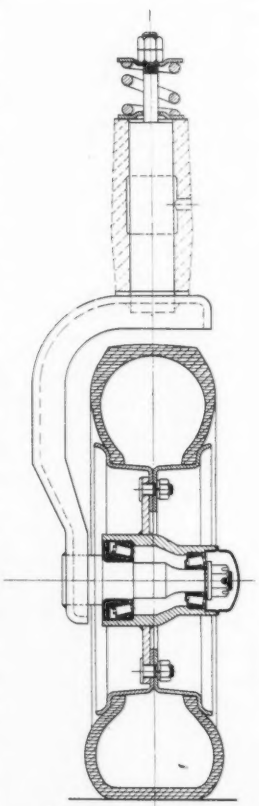

Fig. 16 Bearings in wheels of a tractor mower

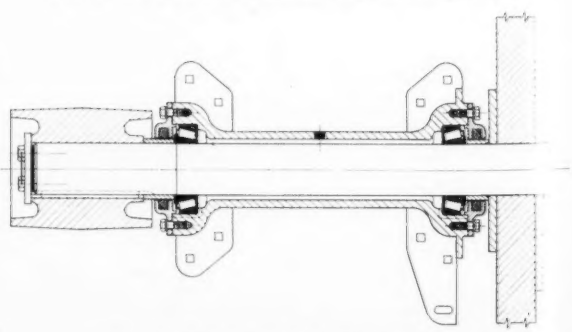

Fig. 17 Cylinder shaft of a forage harvester

Fig. 3 shows the rear axle of the same 18-hp tractor. Bull

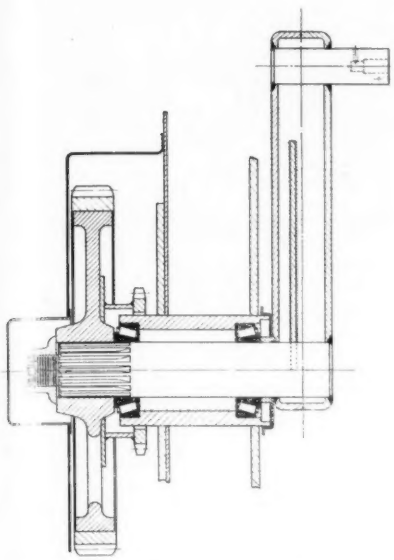

Fig. 18 Crankshaft of an automatic hay baler

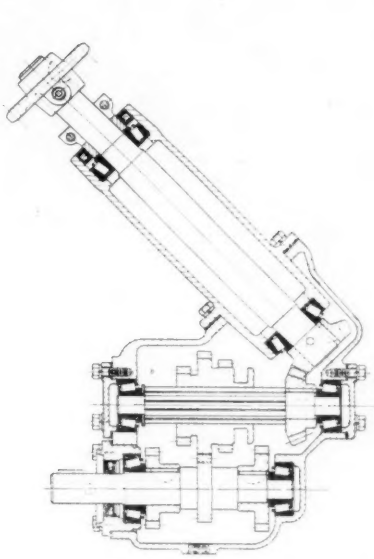

Fig. 19 Bearings application in a hay rake gearbox

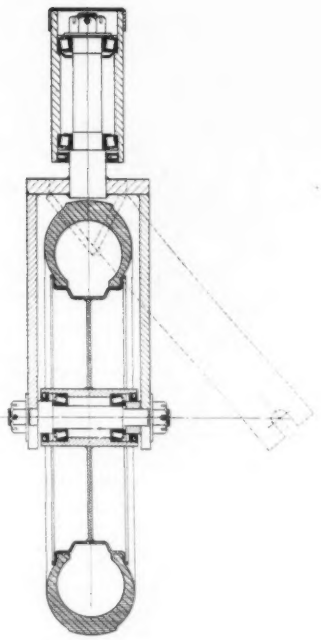

Fig. 20 Tapered roller bearings in hay rake wheels

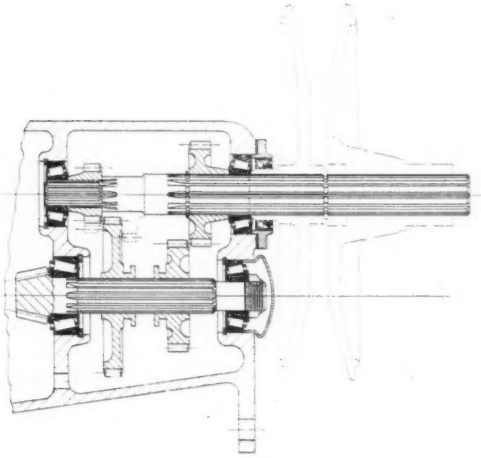

Fig. 21 Transmission of a self-propelled combine

gear performance has been greatly improved by means of the tapered-bearing straddle mounting of the bull pinion. The elimination of deflection in the shafts supporting the bull pinion and gear is a most important factor in obtaining satisfactory gear service with comparatively narrow and low cost gears. The one-shot-per-season principle of lubricating these tractor units is, I believe, taken for granted, but you will notice many similarly lubricated units used in the implements illustrated in this paper which feature has come into implement designs very recently.

A very important development in tapered roller bearing truck roller applications is shown in Fig. 4. In track-type tractor truck roller applications, the effectiveness of the sealing and lubricating means in excluding dirt, mud, and water from the bearings is unanimously recognized as the measure of the success of the track roller bearing. It can be said that a suitable seal prevents contamination of the lubricant and that the

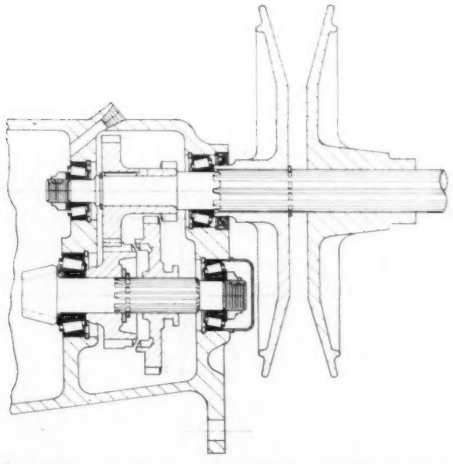

Fig. 22 Bearing application in a self-propelled combine transmission

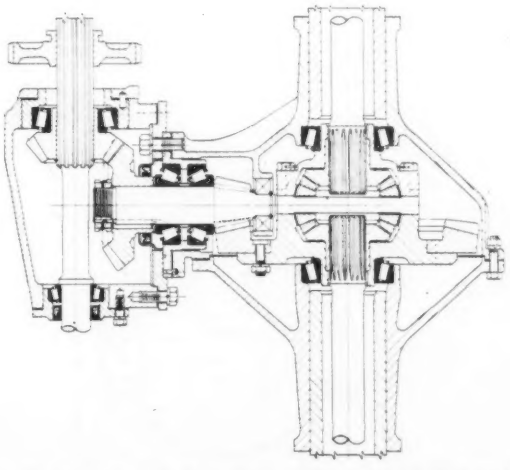

Fig. 23 Center portion of propelling axle of self-propelled combine

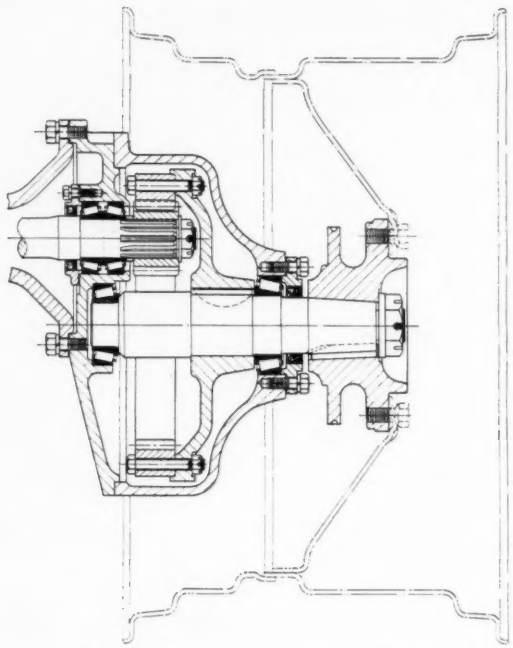

Fig. 24 Outer ends of axle shown in Fig. 23

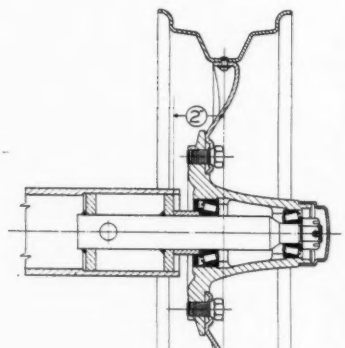

Fig. 27 Wheel design for pull-type combine

lubricant preserves the life and prevents wear of the sealing elements so that each is dependent upon the other. The attitude in this industry regarding the providing of an adequate seal has changed from one wherein the fear of imposing prohibitive initial costs has currently been supplanted by a belief that the operating economics definitely require an effective seal regardless of its initial cost. This type of design has now been in service for upwards of 10 to 12 years with outstanding success. Certain features of this seal design are the development and property of one particular farm machinery company and permission has been obtained to exhibit the design primarily to illustrate the principle and emphasize the importance of using a type of seal as required to obtain an end result equitable to the cost and importance of the equipment involved. I am sure events will prove that this industry cannot afford to use any less effective type of seal in truck roller applications. By the same token I expect that events will surely point out in other dirt-exposed bearing applications, as, for example, disk harrows, disk furrow openers, disk plows, one-way plows, and the like, where the greatest utility and final economy will be best served by the adoption of fully satisfactory means of sealing and lubricating.

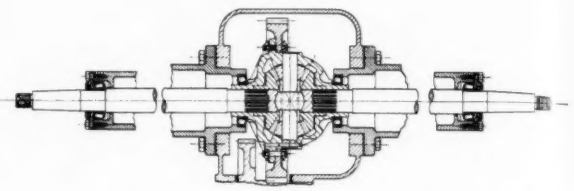

Fig. 25 Bearing application in single-reduction propelling axle of self-propelled combine

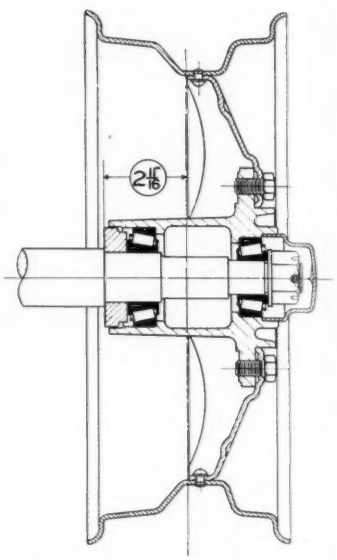

Fig. 26 Wheel design for pull-type combine

Tillage Tools. Fig. 5 shows the mounting of bearings and the type seal used in a disk harrow. This seal is similar to the type used in the foregoing truck roller of the track layer tractor. Originally this design had low-cost seals and high-cost bearings, but the design did not provide satisfactory protection against dirt. This current design seal now in the seventh or eighth year of use in this disk harrow has reduced the over-all initial unit cost by allowing the use of lower cost high production bearings. Furthermore, the bearing life has

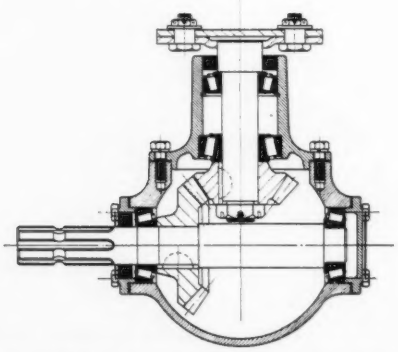

Fig. 28 Main drive design for pull-type combine

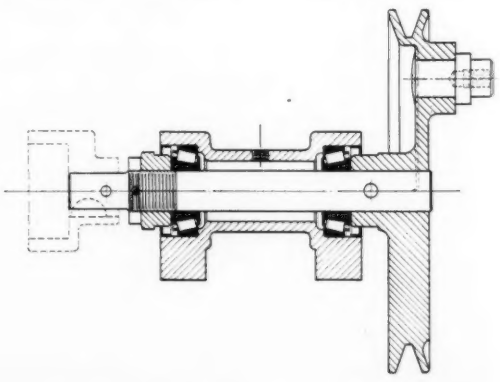

Fig. 29 Bearing application in combine sickle drive

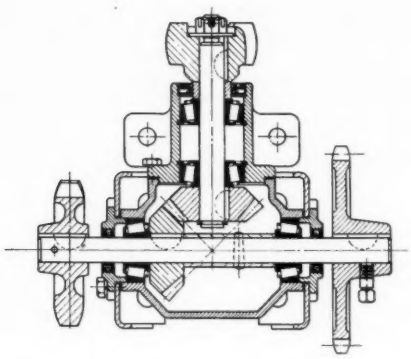

Fig. 30 Main drive design for corn picker

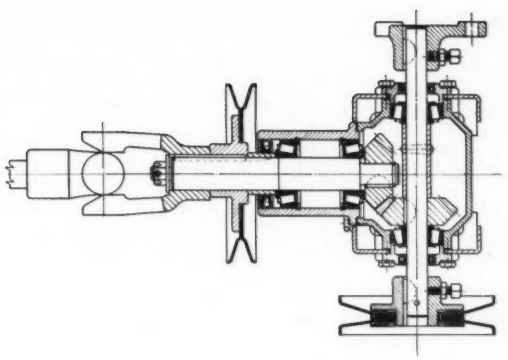

Fig. 31 Design for corn picker snapping-unit drive

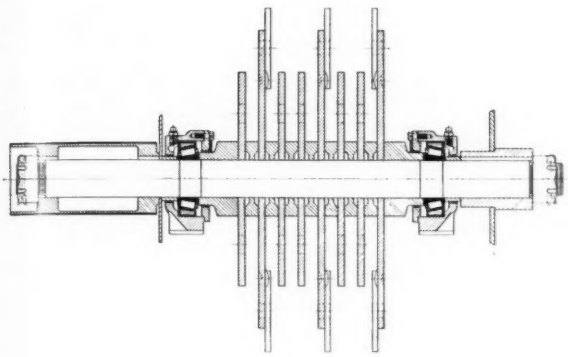

Fig. 32 Cross section of hammer mill cylinder shaft

been greatly increased. The over-all costs of the design are, of course, favorably affected by reason of the need for only two seals and two bearings per gang. Relubrication periods are lengthened by the large lubricant capacity.

Fig. 6 shows a concave rolling jointer, as used on moldboard plows in place of two parts, the coulter and the jointer. It is reported to reduce the side load on the plow heel plate, and also the draft. The combined thrust and radial load characteristics seem to indicate the tapered bearing a good choice. A good dirt seal and adequate lubrication are required.

A mounting of bearings in the wheels of the one-way type of disk plow is shown in Fig. 7. The bearings in this design have been spaced much closer than in older designs because tapered roller bearings will allow the closer spacing and shorter and lighter wheel hubs. The success of the bearing is of course dependent on the use of a good lubricant and a good seal to protect the bearings from the lapping action of dirt, and also on the feature of relubricating as needed. The penetrating and abrasive qualities of soil vary widely in different localities. Therefore, more frequent relubrication may be required in some localities where conditions are most severe.

Fig. 8 shows a section through the design of a tapered roller bearing thrust block for a one-way disk plow. Good lubrication and a good dirt seal of efficient design and satisfactory life is very important in this application.

In Fig. 9 is shown a tapered bearing application in the hanger bearing of a one-way disk plow. Good dirt protection and lubrication are important.

The construction used in a one-way disk plow, similar in principle to the disk harrow shown in Fig. 6, is shown in Fig. 10. This design provides for mounting the bearings in a rotating tubular housing which has the disk blades on the outside diameter of the tubing. This reduces the number of bearings and seals required and provides a very large lubricant reservoir, which is an important factor in lengthening relubrication periods.

Fig. 11 shows the disk plow spindle where the individual disk is mounted on its own tapered bearings. In this case the rotating flange extension which is integral with the disk spindle is very beneficial in shedding dirt. An effective dirt seal is very important in this application and the rubbing surfaces should be smooth to prevent rapid seal wear. A good grade of grease has been satisfactory, but disk plow service is re-

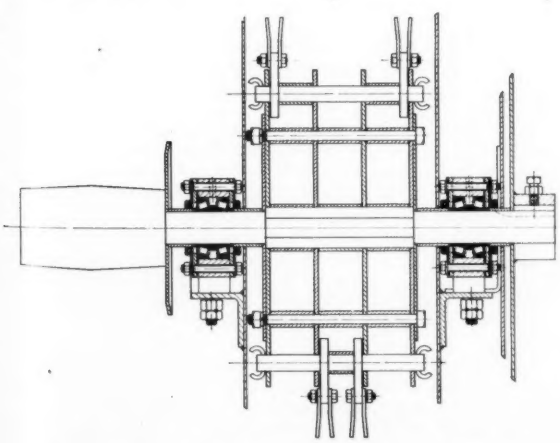

Fig. 33 Alternate application to design shown in Fig. 32

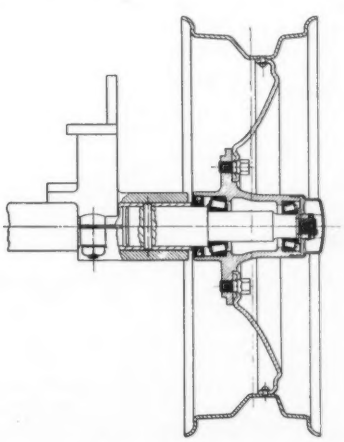

Fig. 34 Bearing application in manure spreader wheel

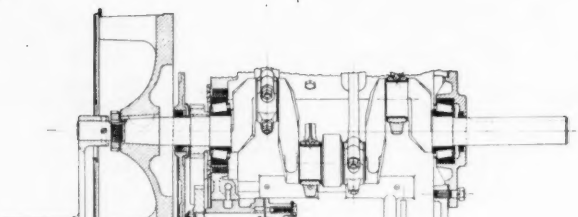

Fig. 35 Tapered roller bearings in 4-cylinder gasoline engine crankshaft

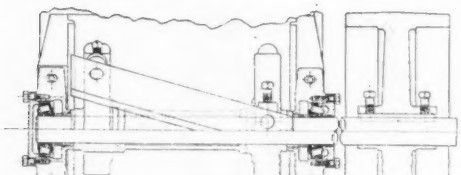

Fig. 36 Bearing mounting for ensilage cutter knife shaft

garded as most severe and frequent relubrication is recommended by the manufacturer. One of the most important of the lubricant functions is to lubricate the seal and prolong the seal life, and the most effective insurance developed thus far to obtain these results has been frequent reapplications of the lubricant.

Planting Equipment. The application of tapered bearings in a power grain drill wheel is shown in Fig. 12. The tapered bearings provide a light compact low-cost wheel hub design and allow towing the grain drill at high speeds. Good seals and lubrication are definitely important to protect and prolong the bearing life. Stationary axle applications of this type lend themselves to the simplified designs and easy assembly obtained in this application.

Fig. 13 shows the application of tapered bearings in a disk furrow opener. This is used for making beds in conjunction with a corn planter or the like. The tapered bearings, we understand, have considerably longer life than the chilled-type bearings formerly used, but here again the importance of a good seal, good lubrication, and frequent lubricant reapplication cannot be overstated. The simplified machining and assembly will be of interest.

Fig. 14 shows the application of tapered bearings to the drive shaft and tine shaft of a rotating tiller type cultivator providing exceptionally good weed control in muck soils where weed growth is rapid and rank and where high value crops, such as onions, carrots, lettuce, and the like justify unusual methods. The bearing mounting, spacing, and seals are similar in general design to those used in the deep type rotary tiller, and the economical machining and assembly offered by tapered roller bearings is well illustrated in this design.

Hay-Making Equipment. The mower drive and pitman shaft of a tractor-powered mower are shown in Fig. 15. The bearing housing on the lower shaft consists of steel tubing welded into the frame, which becomes a part thereof providing a sturdy economical construction.

Fig. 16 shows the application of bearings in the wheels of a tractor mower. The principle of incorporating a seal which provides the rubbing seal contact on the extended bearing cone or inner race is at least 30 years old to my personal knowledge. This type of seal was used on automobile front wheels before the time of the front wheel brake and probably illustrates one of the first types of the so-called self-sealed bearing. Seals are made to press into the wheel hub, thus allowing the manufacturer the privilege of using an oil seal where required, or a dirt seal where required or adapting the application to suit the conditions involved. Relubrication means is generally provided as a matter of extending seal and bearing life to the maximum and in a wheel the hub cap may be used for this purpose.

Fig. 17 shows the application of tapered bearings to the cylinder shaft of a forage harvester. The designer of this unit has provided for abundant lubricant storage as well as a rigid compact assembly unit. Alignment of bearings is no problem in this design.

The application of tapered bearings to the crankshaft of an automatic hay baler is shown in Fig. 18. The loads required to compress the bales are transmitted directly to the tapered roller bearings. The principle of the compact rigid tubular bearing housing provided to support the overhung crank, together with the large, stiff shaft, provides an ideal condition for tapered roller bearings. This method of self-containing all the heavy loads in a small compact unit makes for lighter construction throughout the balance of the machine. The gear lubricant lubricates the bearings, thus providing one-shot-per-season construction.

Fig. 19 shows a hay rake gearbox having low and high raking speeds and a tedding speed. One-shot-per-season lubrication is a feature of this design, as well as simplified and economical machining and assembly. The higher speeds and heavier duties imposed on hay rakes by operation with tractors are important factors in the requirements of modern design units of this type.

Fig. 20 shows the application of bearings in the caster wheel of a hay rake, desirable by reason of the heavier requirements of high-speed tractor service.

Grain Harvesting Equipment. Fig. 21 illustrates a transmission for a self-propelled combine having 45,000 in-lb skid torque capacity requirement at the driving axle. This again illustrates the principle of one-shot-per-season lubrication. The high speed or upper shaft has what we call the direct-type tapered bearing mounting. This mounting has been favored in many cases because of the belief that the machine work may be most economical. The lower shaft has what is known as the indirect tapered bearing mounting and is required in order that under normal operation the thrust from the spiral bevel pinion be taken by the bearing adjacent said bevel pinion.

A transmission for a self-propelled combine of similar capacity to Fig. 21 is shown in Fig. 22. To obtain a shorter over-all unit length and a continuous running oil thrower gear, this design incorporates a constant-running gear on the bevel pinion shaft. Both upper and lower shafts have the indirect tapered bearing mounting. This results in the elimination of the bolted-on bearing cap of the former design to locate the right-hand high speed shaft bearing which provides several economies, namely, the cost of the cap, the cost of milling the end face of the unit, the cost of drilling and tapping the screw holes, and the costs of the holding screws. The indirect mounting, therefore, is well worth a comparison with the direct mounting.

Fig. 23 shows the design of the center portion of a propelling axle for a self-propelled combine. Considerable reduction is required to obtain low gear speeds of around 1 mph required in rice field service and this is obtained by the double reduction type of axle. Fig. 24 shows the outer ends of this axle having an internal gear reduction and the mounting of the propelling wheel.

Fig. 25 shows the application of bearings in a single-reduction propelling axle design for a self-propelled combine, where apparently a large proportion of the total reduction is taken ahead of the axle. The single-row mounting of the axle bearings requires abutting the axles. This principle has been used in automobile axles for forty years. No doubt many million cars on the road today have this principle incorporated in the rear axle.

The design of a wheel used on the pull-type combine for a maximum load of approximately 3500 lb per wheel is shown in Fig. 26. Considerable reduction of axle diameter and bearing cost is obtained by the offset bearing design which provides for a reduced axle bending stress and low over-all wheel and axle cost.

Fig. 27 also shows a design of a wheel for a pull-type combine for a maximum load in the neighborhood of 2000 lb per wheel. A series of tests were made by our company with this wheel design using a 1⅜-in diameter cold-drawn 1045 unheat-treated axle. The object of these tests were to find out what benefits in increased axle carrying capacity could be obtained by reducing the bending moment on the axle to a minimum. In these tests it was found that the greatest benefits were obtained by reducing the axial distance from centerline of tire to axle support to a value in the neighborhood of 1 in. These tests were reported in a paper given by the author at the SAE national tractor meeting in September, 1947, in which paper an effort was made to compare the stationary with the rotating type of stub axle, which later may offer a solution for a simplified dual wheel mounting.

A design of a 15-hp main drive for a pull-type combine is shown in Fig. 28. Units of this type are designed for one-shot-per-season lubrication. This principle of one-shot lubrication per season in such units has been eminently satisfactory and enables the designer to provide the user with machinery which does not require an hour or two of conditioning work each day before going into the field.

Fig. 29 shows a tapered roller bearing application to a combine sickle drive. The housing in this design is bored out from each end. Production departments in some plants are equipped to do this type of machine work.

Corn Harvesting Equipment. Fig. 30 shows a design for approximately 8-hp main drive for corn picker service. One feature of note is the transmission of this amount of power through a ¾-in diameter shaft. The Woodruff-type keys in the driving hubs are reported to be quite satisfactory in transmitting this power through the ¾-in shaft. I wish to point particularly to the straight through bore of the housing for the input shaft bearings and another example of one-shot-per-season lubrication.

Fig. 31 shows a design of a 2-hp snapping unit drive as currently used in corn picker service. It is to be noted that this design also shows the straight through bores and snap rings per input shaft bearings as well as successful application of sprockets and pulleys keyed to a ¾-in shaft and, of course, the one-shot-per-season principle of lubrication.

A cross section of a hammermill cylinder shaft incorporating a single-row tapered roller bearing mounting which offers a simplified housing construction, is shown in Fig. 32. The cup or outer race shown is a development which has unusual promise having a three-piece construction comprised of a sandwich with a neoprene filling between the steel raceway and outer shell. A few sizes only of this type bearing have been produced. The first production applications were placed in service some seven or eight years ago and many thousands are now out in service.

Fig. 33 shows a cross section of a hammer mill cylinder shaft incorporating a double-row tapered roller bearing mounting which is an alternate to the former design, and which has been a favorite mounting for upwards of two and a half decades.

Fig. 34 shows a wheel for a manure spreader using the offset type of bearing arrangement which permits of a reduced axle diameter, lighter weights and lower costs. A good seal and good lubrication are desirable.

Fig. 35 shows the application of tapered roller bearings to the crankshaft of a four-cylinder gasoline engine having simplified machining and assembly features. The manufacturer of this engine has produced engines totaling 12 million horsepower equipped with tapered roller bearing crankshafts during the past twenty years, a large number of which have been used on hay balers, combines, and the like.

The ensilage cutter knife shaft for forage harvester and silo filler is shown in Fig. 36. Some 30 years ago, as the silo filler machine business developed, one company perfected the single-row mounting shown on this illustration and has been producing it in volume ever since. As the field forage harvester requirement came into the picture, the same cutter knife shaft assembly was found suitable and adapted to the new requirement. Therefore, this design is really an old timer to most of us, and it is quite interesting to note how the single-row mounting shown has been successful for so many years. The seals and lubricant used are conventional, and there is no reason at this time to doubt their practicability.

Fig. 37 shows another ensilage cutter knife shaft for field forage harvester and silo filler. This illustration is quite similar to Fig. 36, with the exception that the bearings are positioned in the reverse manner. By some strange coincidence this application also was developed some thirty years ago by another company who has proved it to be successful over three decades. The machines are used in the field to harvest and cut up all kinds of forage from ordinary timothy, alfalfa, or mixed hay to the heavier types of feed, such as corn silage and the like. The process includes blowing the chopped material into a wagon in condition for blowing it into the silo without further chopping. This type of machine has been instrumental in saving the farmer a tremendous amount of labor. The interesting thing is how the latest and most efficient machines have made use of the bearing application worked out some 30 years ago. It therefore can be considered that the seals, lubrication, and machining are pretty well proven.

Fig. 38 illustrates a very simple tapered roller bearing mounting for a blower shaft. It happens to be part of a corn sheller and is used to blow the corn stalks some distance from the actual shelling operation. This blower shaft, however, may be typical of blower shafts used in other operations, such as blowing ensilage into silos 60 or 80 ft high. The construction is simple, rigid, and practical, and the seals and lubrication are regarded by this manufacturer as having proved themselves over a period of years.

In conclusion, I would like to say that many of the designs disclosed in this paper are the result of years of experiment and development, and I am deeply indebted to those men in the farm machinery industry who have so generously contributed much of the material for this paper. I therefore wish to express my sincere thanks for their splendid cooperation.

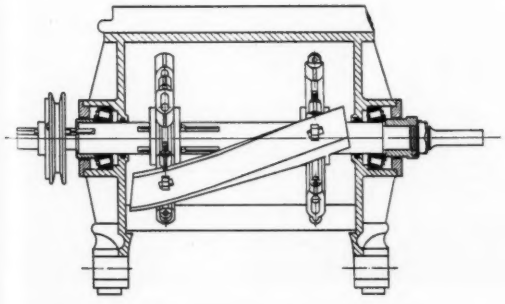

Fig. 37 Bearing mounting similar to Fig. 36

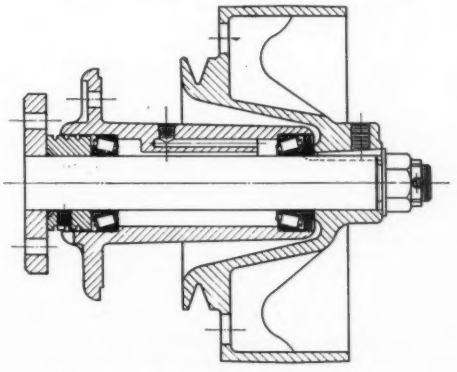

Fig. 38 Bearing mounting for blower shaft

Calculations for Milkhouse Heating Purposes

C. P. Wagner and Marvin Nabben
FELLOW A.S.A.E. MEMBER A.S.A.E.

MINNESOTA winter weather is cold and has continued low average temperatures. In order to apply electric heat to milkhouses it has been necessary to establish the lowest possible minimum standards and then to make calculations for the various conditions which will be met. These calculations are the only method of arriving at conclusions concerning possible cost of heat for any of the various conditions. Testing to confirm calculations is good practice.

If the farmer will understand the need for better insulation, reducing infiltration, and keeping the size of the heater to a minimum, it is probable that he will be satisfied with his electric bill, and the electric power company will have the responsibility of developing a program to render the service.

Engineers and milk sanitation authorities must consider minimum size design for the milkhouses of colder areas. Better sanitation may result from heated houses of smaller size.

Milkhouse heating is desirable to prevent the water system from freezing, to remove ice from the floor, to prevent condensation on the walls, and to provide for personal comfort of the user. Any one or all of the above contribute materially to sanitation improvement.

One farmer says that milkhouse heating is cheap insurance. The protection against slipping and falling on an icy floor or avoiding a single cold makes the installation worth the cost.

It is generally conceded that a controlled temperature of 40 F (degrees Fahrenheit) gives milkhouse protection. Milkhouses of the same size and heated to 40 F will, in Minnesota require from some 2,000 kw-hr to 6,000 or 8,000 kw-hr per season, depending upon their insulation values and degrees of infiltration.

Bad infiltration results from leaving the standard ventilator wide open. Calculations indicate that with electric heating at our temperatures this may waste approximately 500 kw-hr per season.

Our calculations indicate that in Minnesota a milkhouse which can be heated to 40 F by 2,000 kw-hr will require some 3200 kw-hr for heating to 50 F.

The figures which we have given may come as a surprise to agricultural engineers in other areas, since tests of milkhouse heating in those areas show the power required to be much lower.

The Value of a Degree-Day Table. Degree-day tables have been developed as a convenient aid in computing heating requirements. Those already available are mostly for heating to 65 F. Comparable tables for heating to 40 and 50 F, for computing heating requirements for milkhouses, are needed. We suggest that each engineer working on this problem prepare a degree-day table for both 40 and 50 F heating in his own area. The method of developing this table is to show the difference between the daily mean temperature and the desired temperature and to add these differences to show monthly or annual degree-days. For example, if the daily mean temperature for December 13 is 20 F, then there are 20 degree-days per day for a 40 F heating control and 30 degree-days for 50 F heating control. In some months the daily mean is always below the heating temperature. When this is true, the difference between the monthly mean and the heating temperature can be multiplied by the number of days in the month, giving degree-days for the month.

The study of degree-days does not set the requirement for the size of the heating unit required. The highest daily degree-days does assist in determining whether or not a heating element has a capacity within reasonable range. Design minimum temperatures must be taken from heating design information. Usually –20 F is as low as we go in calculating heating requirements, because at that temperature heat loss per hour is about at the maximum, unless there is high infiltration. We do not need to consider the effect of wind losses for lower temperatures.

Degree-Days, Minneapolis Area. In the Minneapolis zone there are 7,850 degree-days for heating to a 65 F temperature. We use –20 F as normal minimum outdoor temperature, for design. We have obtained reliable information to the effect that there are 2,680 degree-days to a 40 F temperature, or something on the order of one-third the number for heating to a 65 F temperature.

The degree-days to 40 F temperature are divided by months, approximately as follows: November, 210; December, 620; January, 810; February, 730, and March, 310. There are six days in January and February with 50 or more degree-days for heating to 40 F.

The degree-day method of approximating heating requirements, for heating to 65 F temperature, is fairly accurate for each season. It may be less accurate from month to month. For heating to a 40 F temperature, the degree-days may be more erratic in distribution, with greater percentage variation from year to year and from month to month than is true with the 65 F basis.

The main point to bear in mind in heating the milkhouse in our area is that the degree-days to 40 F are only one-third of those to 65 F over a heating season. Therefore, heating requirements increase rapidly as the temperature control is set beyond 40 F.

Reducing Heat Requirements. Heat requirements of a building may be reduced in several ways: (1) Locating one or more sides against another building, (2) serving through a vestibule rather than from outside, (3) insulating, and (4) reducing infiltration.

In a 12x14-ft milkhouse built of concrete blocks, we will probably find a total heat loss of some 16,000 Btu per hr at design temperature, –20 F. Cut the actual milkhouse to 12x9 ft 2 in inside, and allow a 3-ft 6-in vestibule on the other side. One side to a barn, not insulated, this house will probably have a loss of 11,400 Btu per hr. Insulate with 4 in of mineral wool and the loss is cut to 4,000 Btu per hr. Change the win-

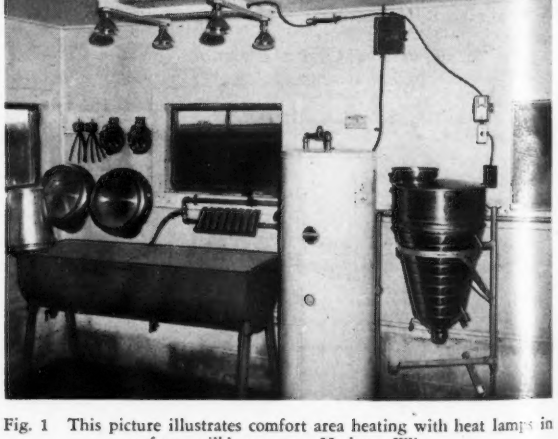

Fig. 1 This picture illustrates comfort area heating with heat lamps in a farm milkhouse near Hudson, Wis.

This paper was presented at the Winter Meeting of the American Society of Agricultural Engineers at Chicago, Ill., December, 1948, as a contribution of the Rural Electric Division.

C. P. WAGNER and MARVIN NABBEN are, respectively, manager and agricultural engineer, farm service dept., Northern States Power Co.

dows to glass blocks to cut infiltration, and the loss may then be as low as 3,000 Btu.

How have we changed the house to obtain this loss reduction from 16,000 Btu pr hr to only 3,000 Btu? For practical purposes, the construction is increased by the materials in the inside wall of the vestibule. The useful size has been cut but not nearly as much as it would appear. We still have a practical-sized unit after the change. Glass blocks allow enough light; their tight fit cuts infiltration. The vestibule cuts infiltration and wind losses on the door side.

These changes in design offer advantages to be considered. Any disadvantage in sanitation will be much more than offset by the improved conditions with economical heat.

The stated range of 2,000 to 6,000 kw-hr per season in the Minneapolis area includes at least some of the improvements to reduce losses as shown by these calculations.

New Milkhouse Location Plans Needed. In almost every milkshed new plans should be drawn showing the preferred location of the milkhouse solely from the viewpoint of low heating costs. Present plans were not drawn with these heating ideas is mind. The refrigeration engineer would make a good plan since he calculates heat to a closer degree than does the heating engineer.

Annual Value of Good Insulation. In the Minneapolis area we can say that the annual value of good insulation and close fitting storm windows and doors can be $40.00 to $80.00 per year, with electricity at 2c per kw-hr, operating to 40 F.

In the Buffalo, N. Y., area the same value may be $18.00 to $35.00 per year with electricity at 1½c per kw-hr, operating to 40 F.

Utilizing Heat Removed from Milk. In Minnesota we noticed about two years ago that milkhouses in which large milk coolers were located were much more comfortable than milkhouses not having coolers. The ordinary milk cooler acts as a heat pump. The refrigerated side is in a sealed-off container or cabinet. The compressor and its heat radiator are located in the room.

We have made calculations on the basis of heat pump data and have reason to believe that the heat radiator has an output of approximately 2.3 kw-hr (7850 Btu) for each 10-gal can of milk handled in the milk cooler without precooling.

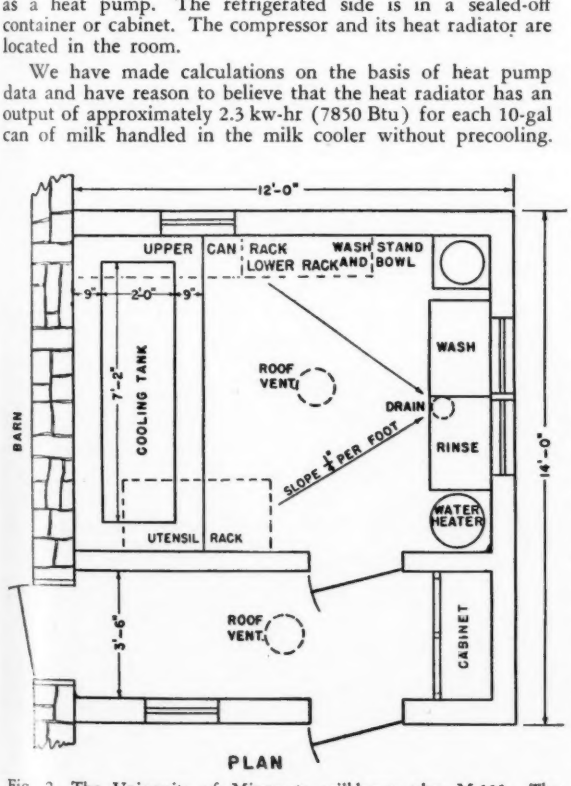

Fig. 2 The University of Minnesota milkhouse plan M-113. The vestibule and placing one side against the barn reduce heat loss.

The milk is brought from 95 to 40 F and the heat is distributed in the milkhouse. Such heat is free and where there are a number of cans of milk to be cooled, it is desirable to conserve this heat. Therefore, we began the study of insulation and its value.

We recommend a –20 F design temperature in order to have adequate heating capacity. A –20 F temperature makes it important to consider insulation. It is not the purpose of this paper to discuss the quantity of insulation but rather the value. In one case a milk cooler handled eight 10-gal cans of milk per day, with enough heat radiated from the cooler to keep that milkhouse almost uniformly at a 40 F temperature.

At first glance this looks like an excellent chance to sell the farmer on insulating to conserve the free heat already available.

For a design temperature of –20 F, or a maximum of 60 degree-days of heating per day, the cooler would need to be handling about 15 10-gal cans of milk per day to provide the heat required to maintain the room temperature of a well-insulated milkhouse at 40 F. If less than this amount of milk is being handled daily during December, January, and February, some means of providing supplementary heat will often be necessary.

Using the Milk Cooler as a Heat Pump. The simplest means of using the milk cooler as a heat pump supplementing its normal operation, is by installing a solenoid valve on the water supply. Control of this valve can be by room thermostat. A ⅜ in valve will discharge 1.1 gpm at 30-lb pressure, or 1.4 gpm at 50-lb pressure. Cost of the small valve will be less than $10.00 and the thermostat about $15.50.

When the room thermostat starts the flow of water, the ice bank in the cooler will melt, starting the compressor unit. In order to get best control we keep feed water away from the vicinity of the refrigerator thermostat.

CAPACITY OF REFRIGERATOR COMPRESSOR NEEDED

Since the water surrounding the ice bank may be about 35 F, the new water may drop some 10 F in temperature. A 10-deg drop in water temperature at 1 gpm will result in release of about 4800 Btu pr hr. The milk cooler refrigerator compressor of ¾ hp or larger would handle this output, and prevent raising the milk temperature.

Assuming the coefficient of conversion or performance of the milk cooler as being only 3, the heat from the electric input will be 2400 Btu, and total heat to the room 7200 Btu per hr. Assuming ¾ kw-hr per degree-day for direct heat, the milk cooler can heat the same milkhouse for ⅓ of ¾, or ¼ kw-hr per degree-day. This ¼ kw-hr includes energy used to cool the milk. Actually the coefficient of performance of the heat pump may be 3.75 or more on some part of this work.

Water pumping costs may be 20 to 30c per month depending on depth of well and electric rate.

At the present time we recommend ¾-hp milk cooler compressors as the smallest to be used under Minnesota conditions. We believe that this limit is required for protection to milk stored in the milk cooler unit.

The ½-hp compressor will handle the Minnesota heat requirements for well-insulated, low-infiltration milkhouses except for about 6 days of January and February.

The ½-hp compressor will serve the areas of the north half of states from Michigan east. Compressors of ⅓ hp might serve areas with more southern location, where adequate to properly cool the volume of milk handled.

Installing a hand valve in front of the magnetic valve will allow control of the water flow through reduction of pressure. The imposed pressure can be such that the amount of flow will be just below the Btu capacity of the compressor unit. By keeping below the capacity, the ice bank will be sustained in part and the milk temperature will be protected. The heat output will also be sustained.

A. A. Pfingsten suggests that in many cases a farmer may not have adequate water supply, nor a method of wasting

water through the milk cooler. In such cases an additional radiating system can be installed in the milk cooler, with the piping extended to the barn, installed in the earth, or arranged to provide some other method for transfer of heat to the milk cooler and thence to the room. Certainly this possibility should be considered.

Methods of Applying Heat. There are a number of methods of obtaining, supplying, or conserving heat from electric devices in the milkhouse. Some of these are (1) Conserving existing milk cooler heat, (2) The milk cooler as a heat pump, (3) direct radiation, (4) storage water heater, (5) radiant heat, wall or floor, (6) heat pads, and (7) the heat lamp as supplement for personal comfort.

The conserving of existing heat from the milk cooler needs no further discussion. Additional use of the cooler system as a heat pump is still in the experimental stage. We have listed one farm with good drainage where we expect to carry on this study during the coming winter.

Fan-type, direct-radiation heaters seem in some ways to be our best possible unit for supplementary heating to the temperature suggested. This heater is 100 per cent efficient. If selected in reasonable capacities, 1,500 to 2,000 watts, and connected 220 volts, the heaters will not seriously affect the farm wiring or the transformer from the standpoint of voltage drop. Some units are made available with the thermostat within the unit frame. The best connection seems to be the remote thermostat located on the wall which touches the barn, and about midway between floor and ceiling.

Many electric power companies offer special rates for off-peak storage-type water heaters. Under most of the rules there is no provision as to the use of the water. Therefore, there is no reason why these rates should not be used with standard water heaters and then the hot water used for heating the milkhouse. At first glance this method of developing heat for the milkhouse may seem very attractive. On second thought, if we apply engineering principles to the heating, the installation may be considered much less attractive. We do not mention this with the idea of excluding this type of heater. Certainly, however, there are indications of the need of considerable research to prove the value of this type of heater, and its economy.

RADIANT HEAT BY ELECTRICITY OR HOT WATER

Radiant heat in the wall or floor could be through the use of electric heat cables or copper tubing with hot water. These units could be placed in the plaster and operated in a satisfactory manner. Radiant heat to 40 F may not be as successful as it would be at the higher temperature of home heating. The main advantage of home heating with radiant heat is that we can operate at a much lower temperature with greater comfort. This condition will not be found in our milkhouse heating problem.

One of the rubber companies has provided a rubber heating pad. The pad itself is the heating element. This method of heating the milkhouse has been offered in our area to some of the non-technical sales agencies, particularly the appliance sales section of Land O'Lakes Creameries. The value of such heating equipment should be proven. The connected load should be kept down to about that suggested for the direct-radiation process. At the present time we see no particular economy or heating value in this method of handling heat in our milkhouse unit.

A 40 F temperature may not provide enough comfort for the operator. If so, it is preferable not to turn up the thermostat or increase the heat in the room. Instant heat to a comfort zone can be obtained from the radiation of a heat lamp, without increasing the general temperature in the milkhouse itself. Two, four, or six of the R-40 heat lamps should be connected 110-220 v in order to balance their load across the 220-v service. Switching is accomplished with a two-pole, 220-v switch. There is now available a new unit having the appearance of a fluorescent lamp fixture. The fixture is equipped with tubular infrared heat units. These units will serve the same need as is served by heat lamps.

It has been suggested that the heat lamp or infrared heat units be controlled by a timer. This timer can be set for a predetermined operating period. Without it, forgetting to turn off a heat unit may seriously affect the electric bill.

Wiring Requirements. In this milkhouse heating development we are adding a considerable amount of equipment in the area of the dairy barn. The milk cooling unit, supplementary heat, heat for comfort area and water heating may go to upward of 5500 w, a 25-amp load at 220 v. If all of this load is connected at 220 v and the dairy barn is 550 ft from the transformer, it will require a No. 4 conductor to carry this load alone. A No. 6 conductor would carry the load 350 ft. If any of the load is in unbalance, the conductor size must be increased and the larger conductor run from the dairy barn area back to the transformer. We must add enough capacity to carry the other loads in that area. Poor wiring to the dairy barn and milkhouse area will result in considerably lowered efficiency in the operation of this equipment. Almost every farm in the entire country equipping the milkhouse with heating equipment in addition to the milk cooler and utensil washing water heater will need new larger wiring to the dairy barn and milkhouse zone.

Heating System in Unbalance. We can definitely say that for relatively small areas as compared with the average home, any system other than warm air is in unbalance and therefore more or less inefficient. The statement is more true for lower temperature heating.

Hot water heating for a milkhouse will be in extremely bad unbalance if water-storage capacity is more than a few gallons (as in the electric radiator heater). Uncontrolled water flow or too large heat units are undesirable for our conditions.

SUMMARY

1 Milkhouse heating requirements may be minimized in construction by building the house to minimum size, with one side against the barn, a vestibule on another side, glass block or close-fitting storm windows, insulation, and vaporproofing.

2 Heating requirements may be minimized in operation by holding the temperature to 40 F, and by restricting ventilation.

3 These economies will make it possible to heat the house with only one-third to one-fifth the amount of electricity required for some houses.

4 The well-insulated house of 1000-1200 cu ft can be expected to require about ¾ kw-hr of direct heat per degree-day.

5 The same milkhouse may be heated with the milk cooler operating as a heat pump, for ¼ kw-hr or less per degree-day. This will include the energy used to cool the milk.

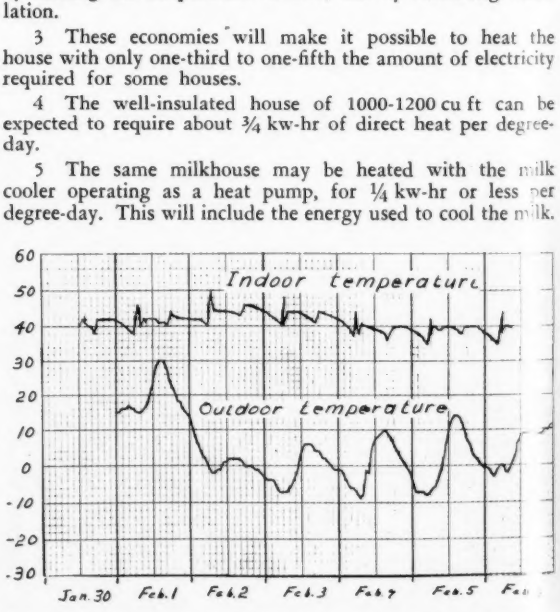

Fig. 3 Temperature variation chart for a well-insulated milkhouse for a period during which outdoor temperatures varies from 30 F to −1 F. Milk cooler heat only eight cans per day. Not operating with water input as a heat pump

Instrumentation for Animal Shelter Research

By C. F. Kelly, T. E. Bond, and C. Lorenzen, Jr.
MEMBER A.S.A.E. JR. MEMBER A.S.A.E. MEMBER A.S.A.E.

RESEARCH in animal shelters in many cases involves the measurement of heat flow. This is especially true where the ventilation requirements and the effect of various environmental conditions on heat loss from livestock are being studied. Studies of animal shelters during the past three years on a cooperative basis between the U. S. Department of Agriculture and the Divisions of Animal Science and Agricultural Engineering of the University of California, have given opportunity for the use of various instruments in measuring the variables making up the environment and for the measurement of heat flow. Experiences in both fields will be discussed in this paper.

Temperature and heat flow are so closely related that one definition describes temperature as the potential controlling heat flow. Instruments for measuring one are usually useful for measuring the other. For estimating the rate of heat loss by convection, one must know the dry-bulb temperature of the air and the rate of air flow. The calculation of the rate of heat loss by radiation involves the temperatures of surfaces or the direct measurement of emission by means of suitable instruments. The estimation of total heat loss and moisture removal through a ventilation system brings in another variable, the wet-bulb temperature of the air. Small heat-flow meters are available for measuring directly the heat flow through surfaces. Radiometers are available for measuring total solar and sky radiation and the intensity of radiation from a surface. Instruments such as the globe thermometer and the Kata thermometer measure the combined effects of temperature, radiation, and air flow.

Measuring Dry-Bulb Temperature of the Air. Three problems, in connection with measuring the dry-bulb temperature of the air, may arise in animal shelter research: (1) location of instrument, (2) measurement of dry bulb without effect of radiation from or to hot or cold surfaces in the vicinity, and (3) measurement of rapidly changing temperatures such as are encountered with the cycling of an off-and-on air-conditioning unit or with an oscillating fan used for air circulation.

If the effect of environment on an animal is being studied, there would seem to be no question but that the instrument should be located so as to measure the temperature near the animal. In many cases, however, this is difficult to do without danger of damage to the instrument or injury to the animals themselves. Often a compromise is made by locating the instrument above the animals. In studies with hogs in the California psychrometric chamber and with cattle in a shelter cooled with a "desert cooler", a difference of several degrees between the temperature at animal level and a few feet above the animal was not unusual. Cages or shelters for the instruments were constructed as shown in Fig. 1, for the hog studies and cattle studies, and have proved quite satisfactory. Old tire casings nailed to the posts will protect cattle from being bruised on sharp corners.

The effect of radiation on the dry-bulb temperature indicated by mercury thermometers, recording thermographs using a Bourdon tube, and thermocouples, is covered extensively in the literature on pyrometry, but the importance of this factor at ordinary temperatures is not always realized. If the walls, sky, or other features of the "surround" are at a temperature higher or lower than the air temperature, the thermometer bulb or the thermocouple junction will gain or lose heat by radiation, and indicated temperature will not be the true air temperature. Mulliken[1]* describes twenty-six methods of eliminating radiation errors in the measurement of gas temperatures. Lorenzen, in a paper before this Society in December, 1948[2], discussed the two methods most applicable to our work —the shielded thermocouple and the butt-welded thermocouple of small diameter. Probably the most effective method is a combination of the two—a thermocouple of as small diameter as can be conveniently handled without breakage, enclosed in a single or double cylindrical shield of polished metal. A butt-welded copper-constantan thermocouple of 30-gage wire, with two concentric shields, the inner ½ in in diameter by 2 in long and the outer 1 in in diameter by 2 in long, has proved satisfactory under the conditions of solar radiation encountered in the Imperial Valley of California, when oriented so as to give maximum shielding and greatest air flow at the junction. The fine-wire thermocouple leads need be only a few inches long and can be soldered to larger wires to cut down the electrical resistance of the circuit. The shields should not be smaller than ½ in in diameter. A smaller diameter may slow down the air flow and introduce another error due to the low rate of heat transfer by convection between the thermocouple and the air.

Sudden changes in temperature of several degrees in two or three minutes are not ordinarily encountered when measuring the weather, and usually a recording instrument using a bimetallic or Bourdon tube sensitive element will respond fast enough. However, in measuring the heat loss from animals, large errors may result if rapid temperature changes are not detected and measured. Readings made at Davis with a heat-flow meter indicated that the surface temperature of animals may lag behind air temperature, where sudden changes in air temperature are encountered. At an ambient temperature of 80°F, the surface temperature of a 200-lb hog is about 92 F[3]. The "potential" control-

This paper was presented at a meeting of the Pacific Coast Section of the American Society of Agricultural Engineers at Davis, Calif., in February, 1949.

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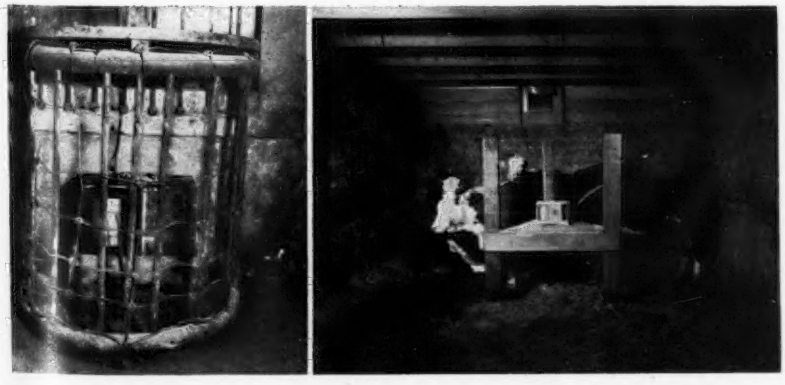

Fig. 1 Cages suitable for protecting instruments used for recording the dry-bulb temperatures and relative humidity at the level of the animals. *Left*: Type used at Davis, Calif., in studies with hogs. *Right*: Type used at El Centro, Calif., in beef cattle studies

* Superscript numbers refer to appended references.

ling convection heat loss is 12 deg. If the average air temperature is 80 F, but is varying from 75 to 85 F over periods of a few minutes, the "potential" is also varying from 17 down to 7 deg (providing the surface temperature of the animal does not change), and the results of observations with a heat-flow meter or other heat-measuring device will not be consistent for the 80 F "average" temperature. Fig. 2 shows the surface temperatures of back, belly, and side of a 200-lb hog in an environmental temperature averaging 80 F, but varying between 75 and 85 F every 6-min period.

The surface temperature observations were made with a Hardy dermal radiometer, with which a reading can be made in from 10 to 15 sec, and the air temperature observations with a 30-gage copper-constantan thermocouple.

Surface Temperatures. In farm structures the measurement of surface temperatures may be necessary for the calculation of heat transfer relating to both buildings and animals. Again the thermocouple is very useful, but its application to the many types of surfaces involved is rather difficult. The requirement is that the thermocouple junction take on the temperature of the surface being measured, without changing the character of the surface with regard to convection loss, emissivity, or evaporation qualities. In measuring surface temperature of animals, a further requirement must be met that the circulation beneath the skin is not impaired.

For all types of surfaces the size of the thermocouple wire should be small, with a junction as small as possible. Thirty or 36-gage wire, with a butt-welded junction, has been found to be about as small as can be conveniently handled, although junctions of 40-gage wire have been accomplished. For attaching to a wood surface, thumbtacks spaced about 4 in apart, with the wire stretched between them, have been found to be more satisfactory than attaching the thermocouple to the surface with some type of adhesive tape. The junction and several inches of the leads should be pushed into the wood so that the wire is about half buried. Studies of the inside surface temperatures of hog shelters, checked with a radiometer, using handbook data for emissivities, have indicated that this method will give consistent and fairly accurate results. The temperature of concrete walls can be obtained by the same method, except that the adhesive tape will be necessary for holding the thermocouple in place, and a slight scratch in the surface should be made to partially bury the wire before attachment. Soldering to a metal surface is practical where temperature differences between surface and air are small, but installation should be done some time before the observations are made, if possible, so that the solder can tarnish and approach the emissivity of the wall surface. Peening the couple into the metal is generally conceded to be a better method, especially for high temperatures[4]. Kratz and Broderick[5] have discussed the use of thermocouples in measuring wall temperatures in detail and describe a method for determining the amount of error involved in a given case.

For determining the surface temperature of swine and cattle, both over and under the hair, the touch thermocouple shown in Fig. 3 has been used. The observations have checked very well with the Hardy radiometer. The thermocouple, of 30-gage copper and constantan wire, is supported on cotton threads under slight tension between the legs of a ⅛-in bronze rod "U". A one-pint thermos jar serves as both a handle for the instrument and as an "ice pot" for the cold junction reference. By having the cold junction reference at the instrument, long, low resistance, copper leads from the instrument to the potentiometer can be used.

Wet-Bulb Temperature. The wet-bulb temperature of the air is especially important in ventilation calculations because, at a given barometric pressure, from this measurement alone the total heat content per pound of dry air can be directly obtained. If the dry-bulb temperature is also known, obviously the relative humidity, dew point, and water content can be easily found. Wet-bulb temperature is ordinarily measured by a sling or aspirated psychrometer. This method has the disadvantage of requiring an observer at the instrument location, thus possibly upsetting the very conditions which it is desired to measure. Hair hygrometers, for measuring relative humidity, are satisfactory for conditions of constant or slowly changing relative humidities. Where rapid changes in total heat content are encountered such as in heat loss measurements from livestock, and where it is desired to record the temperatures, a modification of the thermoelectric psychrometer, as described by Lorenzen[6], has been used in the psychrometric chamber for measuring wet-bulb depressions over the dry-bulb temperature range between 40 and 100 F, at relative humidities between 45 and 55 per cent. Because of the relatively large wet-bulb depression, a single wet and dry junction of 36-gage copper and constantan was used as shown in Fig. 4. Dust from feed, floor, etc., made frequent changing of wicks necessary. Because of ease of replacement, ordinary facial tissues or cigarette papers, folded lengthwise and then crosswise and hung across the horizontal wet junction, were found more satisfactory than wicks of absorbent cotton thread. The facial tissue was perhaps the most effective. At temperatures above 70 F, and air velocities above 400 fpm, difficulty was found in keeping the junction wet unless the vertical distance between water surface in the distilled water reservoir and the wet junction was less than one-half inch. A modification of the instrument shown in Fig. 4, in which a large absorbent wick delivers a continuous supply of water by gravity rather than by capillary

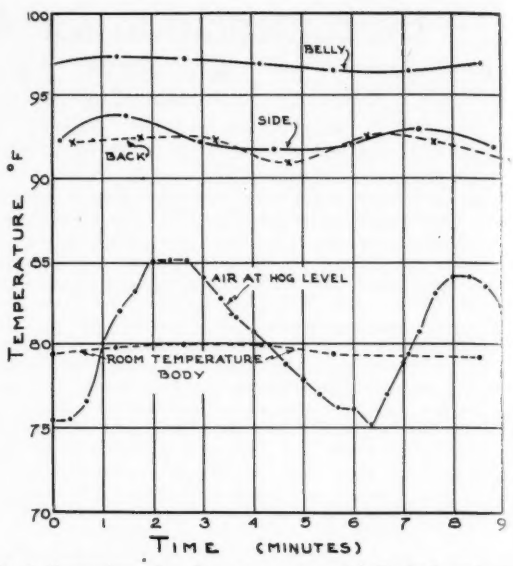

Fig. 2 Comparison of surface temperatures of belly, back, and side of 200-lb hog during periods of rapid air temperature change. Room temperature body is the reference surface for the Hardy dermal radiometer

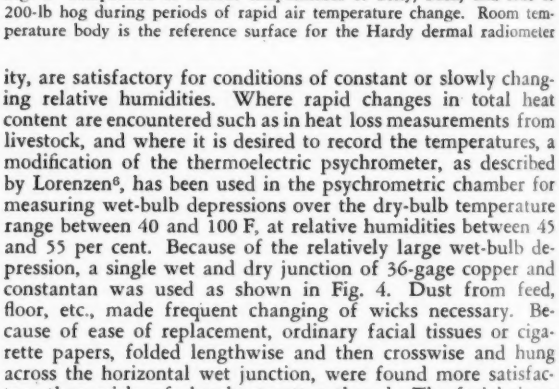

Fig. 3 Touch thermocouple for measuring surface temperature of animals. A one-pint vacuum jar serves as both a handle for the instrument and as a reference junction "ice pot"

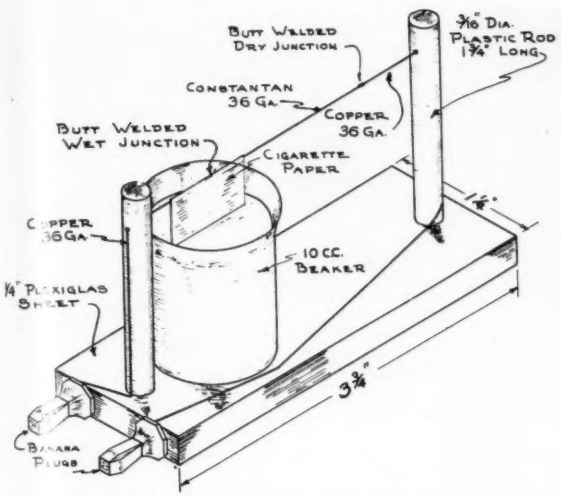

Fig. 4 Diagram of single wet and dry junction thermoelectric psychrometer as used for measuring and recording wet bulb depression in the California psychrometric chamber

action to the small facial tissue wick on the wet junction, has been found to operate successfully at the higher temperatures. While the instrument checked very well when calibrated by comparison with an aspirated pschrometer between the limits indicated above, the effects of other air velocities and vapor pressures on the indicated wet-bulb depression have not yet been determined. The jacks shown in the diagram, commonly known as "banana type", proved to be a convenient method of both mounting the instrument where desired and completing the electrical circuit.

Heat-Flow Meters. Small heat-flow meters have been found invaluable for measuring heat flow by radiation and convection, from walls, floors, animals or the ground. The type used was developed by the division of mechanical engineering, University of California, Berkeley, as a refinement of an instrument constructed by R. L. Perry in 1936, and consists of a thermopile made up of many pairs of silver-constantan junctions, arranged with the "cold" junctions on one side of a thin bakelite slab (1/64 in thick) and the "hot" junctions on the other. The junctions are protected by two bakelite slabs, each also 1/64 in thick, cemented to the thermopile support slab, so that the entire instrument is only 3/64 in thick. Various sizes, from 2 in square to 4 in square, are available. Each instrument also has two iron-constantan thermocouples for obtaining the temperature of the instrument under the cover plates. Each heat-flow meter is calibrated at a standard instrument temperature by the manufacturers and a calibration constant in Btu per hr ft² mv provided. A typical instrument, 2½ x 2½ in, has a thermopile made up of 360 pairs of junctions, a calibration constant of 15.8 Btu per hr ft² mv at a standard temperature of 120 F, a thermopile electrical resistance of 525 ohms, and a thermal resistance of 0.73 F hr per Btu. A curve for instrument temperatures other than the calibration temperature (120 F)) is furnished to correct for the effect of temperature upon thermal conductivity of the bakelite, upon the thermoelectric power of the thermopile, and upon thickness of the bakelite core due to expansion and contraction.

The instrument can be cemented, screwed, or taped to the surface being tested or, in the case of animals, fitted with a handle so that it can be held firmly against the surface. For measuring conduction between an animal and the floor or ground, the meter may be covered with a moisture-proof plastic envelope. The attaching devices should be arranged so as not to obstruct the flow of air across the instrument or prevent the meter from "seeing" the surrounding surfaces, since the instrument measures heat lost or gained through both convection and radiation. For measuring heat flow through a floor of a shelter, protection of the instrument from both mechanical damage and moisture is necessary. Installation in the instrument cage mentioned before will prevent the animals from stepping on it, and cementing a cover of copper foil about six inches square over the meter and to the floor with Permatex or other waterproof sealer has been found effective in preventing short circuits due to moisture. The foil should be brought to the emissivity of the untreated floor by tarnishing, painting, or other means. A short piece of copper tubing, one end soldered to the foil, serves as a conduit to bring out the electrical leads.

The results of studies of heat loss from animals by radiation, convection and conduction, as measured by a heat flow meter, have been described in a previous paper.[3]

In the use of small meters for this purpose, slight errors might be encountered because the meter, being impervious to moisture, will stop heat loss from the animals' skin due to evaporation. Fortunately, it is believed swine and cattle lose little moisture through the skin, minimizing the error. Care should be taken to hold the meter only on dry areas of the animal.

The time the instrument is held in place on the animal should be sufficient to allow the heat transfer rate to reach a steady state, but not so long as to materially affect the animal's subcutaneous circulation. The ambient temperature will have some effect on the rate at which the instrument approaches the steady state with regard to both temperature and heat flow. For instance, at an air temperature of 90 F, the animals' surface temperature will be about 97 F, and the instrument will have to increase in temperature 7 deg. This, in practice, takes about one minute. However, at an air temperature of 40 F, the same hogs' surface temperature will be approximately 82 F, the necessary instrument temperature rise will be 42 deg and the time to reach steady state will be about three minutes. Studies by the University of California indicate that when the meter in air at 78 F, is placed suddenly on a surface at 122.8 F, it will take 2.1 min for the temperature of the heat meter to reach 95 per cent of the steady state meter temperature and 1.4 min for the heat flow through the meter to come within 5 per cent of the steady state heat transfer rate. The fact that in observations with hogs, using a meter 2x2 in, the instrument temperature and rate of heat flow after the first two or three minutes remained practically constant, is an indication that hog surface temperature under this instrument was affected very little.

Flat Plate Radiometer. The flat plate radiometer is a modification of a heat-flow meter, used for measuring the total solar and sky energy incident upon a flat surface. Both long and short-wave radiation is received and integrated over the entire hemisphere. This instrument, developed by J. T. Gier and F. A. Brooks of the University of California, has been found very useful for measuring the heat load on animals and structures from both the sky and ground, and for comparing the efficiency of shades in cutting off solar radiation.

A standard heat-flow meter, if held horizontally in the sun, will receive radiant energy from both the sky and the ground, and, because its temperature will rise above that of the air, will lose heat by convection. The thermopile in the meter will indicate heat flow through the meter from the side receiving the most radiant energy to the opposite side, providing convection loss from both sides is the same as when the instrument was calibrated. By making one side of the meter highly reflective, radiant energy from only the black side is absorbed, and if the convection losses are equal from both sides, the heat flow through the meter will be a measure of the net energy exchange between the meter and the hemisphere on the black side. If the total energy incident upon the black side is desired, to the net exchange must be added the energy being radiated back by the meter, which is easily calculated by the Stefan-Boltzmann formula. A thermocouple is placed in the bakelite slab for obtaining the instrument temperature. To insure that convection losses from both sides will be steady, a small blower for forcing air across the plate is included in the instrument. Calibration with a standard lamp is made by the manufacturer. The factor for a typical instrument is 20

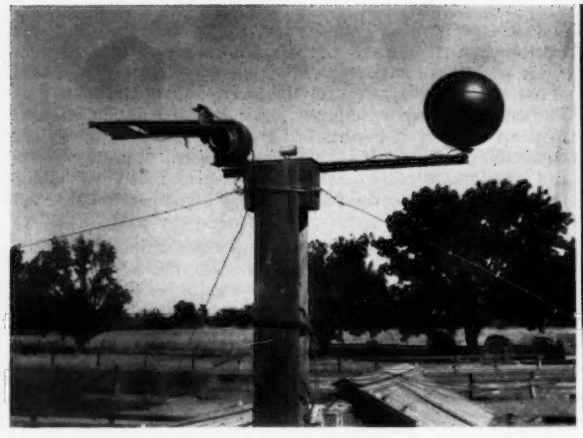

Fig. 5 (*Left*) Instruments for measuring total solar and sky radiation, air temperatures, and globe thermometer temperature, as used in cooperative hog-housing studies at Davis, Calif. Flat-plate radiometer on left; shielded themocouple in center, and 10-in globe thermometer on right • Fig. 6 (*Right*) Radiometers used in California livestock environmental project for measuring surface emissive powers. Gier type on left; Hardy dermal radiometer on right

Btu per hr. sq ft for each millivolt response. A view of a flat plate radiometer is given in Fig. 5, which also includes a globe thermometer and a shielded thermocouple.

Radiometers for Measuring Surface Emissive Power. The determination of the emissive power or rate of radiant energy discharge from surfaces of structures or animals by means of radiometers has the advantage that neither the surface temperature nor the emissivity of the surface need be known. However, if one of these factors and emissive power as measured by a radiometer are known, the other can be found by substitution in the Stefan-Boltzmann formula. In the measurement of radiation from animals, the radiometer is especially useful because it does not actually touch the animal and can not affect the circulation of blood, the surface temperature, emissivity, or evaporation of moisture.

Two types of radiometers used on the California livestock environmental project (Fig. 6) made use of a thermopile, one set of junctions being exposed to radiation from the surface being studied, the other set hidden from the surface viewed and maintained at as constant a temperature as possible in the base of the instrument. A collecting cone or opening in the front of the instrument limits the area of the surface viewed. Radiant energy from the viewed surface falling on the exposed thermopile junctions increases their temperature above that of the hidden junctions, and an electromotive force is developed, its magnitude depending upon the rate of emission from the surface. This in turn, of course, is a function of the surface temperature, emissivity, and area. If the opening in the radiometer is entirely covered by the viewed surface, area can be neglected.

The radiometer can best be used as a comparison instrument, comparing the radiation from an unknown surface with that from a reference surface of known temperature and emissivity. The electrical response of the instrument to the reference surface is first obtained and then the response to the unknown surface. The difference between the two, in millivolts, multiplied by the calibration factor gives the difference in emissive power between the reference and unknown surfaces. When this difference is added to or subtracted from the emissive power of the reference surface, depending upon the algebraic sign, the emission from the unknown surface is obtained.

It should be noted that two assumptions are made when using the radiometer in this manner: (1) that there is a straight line relation between radiometer response and temperature difference when the temperature differences are small, and (2) that the cold or hidden junctions of the thermopile do not change in temperature during the time elapsed between viewing the reference and the unknown surfaces. Gier and Boelter[7] have, in their studies of the design of radiometers for orchard-heating investigations in California, shown that "the response with respect to energy rate per unit area falling upon the receiving element of the thermopile is approximately linear."

With regard to the second assumption, many observations with a Hardy dermal radiometer on swine in the psychrometric chamber, in environmental temperatures ranging from 40 to 120 F, have shown that if the ambient temperature is fairly steady and care is taken to not touch the instrument except on the handle, the response of the instrument over a one or two-minute period will not change enough to be measurable by a Leeds and Northrup No. 8662 potentiometer. This can be checked easily if the reference surface is again viewed after the measurements are made. If the response to the reference body is the same before and after the observations and the reference body has not changed in temperature, it can safely be assumed that the cold junctions have not changed in temperature. In the psychrometric chamber studies, the practice was followed of making seven readings on the animals, averaging 15 sec per observation, between readings on the reference body.

A portable reference surface that has been found very convenient for use with a Hardy dermal radiometer when working with cattle loose in a corral or hogs in a pen, is shown in Fig. 7. Copper leads as long as desired may be used to connect to the potentiometer, since the ice pot for the thermocouple reference junction is a part of the instrument. A double-pole, double-throw toggle switch is used to switch from the reference surface thermocouple to the radiometer thermopile. The reference surface itself is a brass plate $\frac{1}{8}$ in thick, painted with a mixture of lampblack and turpentine and then smoked with a fuel oil flame. The emissivity of the surface thus coated has been taken to be 0.925. A touch thermocouple is shown on the cap of the thermos jar (Fig. 3.).

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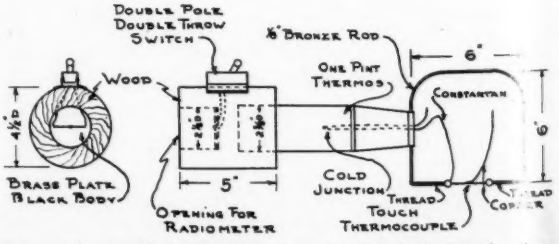

Fig. 7 Diagram of portable reference surface for Hardy dermal radiometer for use with long copper leads, when surface temperatures of livestock loose in a corral are being obtained. Touch thermocouple construction also shown

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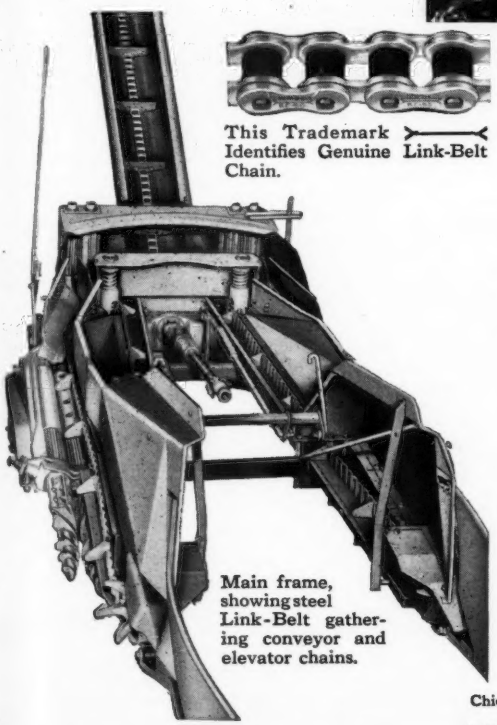

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Animal Shelter Research

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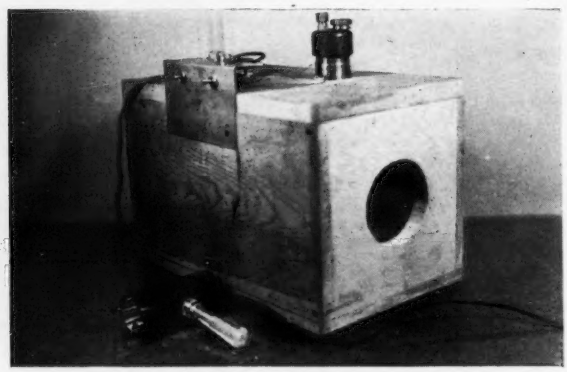

Fig. 8 Device for calibrating small radiometers, consisting of hot and cold surfaces, of known emissivity, ice pot for reference junction and switching arrangement. Hardy radiometer also shown

Calibration of this type of radiometer should be made at frequent intervals when used in barns, feedlots and other dusty locations, because of changes which may occur in the emissivity of the receiver of the sensitive element and the reflectivity of the polished collecting cone. In work with farm structures and animals, it is believed by the authors that calibration in terms of the emissive power of the viewed surface is more desirable than in terms of intensity of radiation because the results are in a more easily used and understood form, and the solid angle of view does not need to be considered.

A calibrating device which has been found effective is shown in Fig. 8. It consists of two blackened surfaces of known emissivity which can be maintained at different temperatures, a thermos jar used for an "ice pot" reference temperature, and two double-pole, double-throw toggle switches for switching the potentiometer to the thermocouples on either of the surfaces, or to the radiometer. The "cold" surface is a blackened brass plate at the ambient temperature. The "hot" surface is a Leslie Cube about 6 in on each edge† filled with hot water. The cone of the cube and the brass plate are both brought to a common emissivity by the turpentine, lampblack and soot method mentioned before. Each surface has a copper constantan thermocouple soldered to it. The Leslie Cube has a stirrer for agitating the hot water, and is insulated by one inch of granulated cork and the wooden box.

In making a calibration, the temperature of each surface is obtained and then the response of the instrument to each surface. The emissive powers of the surfaces are calculated, the temperatures and emissivities being known, and the calibration factor obtained by the formula

$$K = \frac{G_h - G_c}{R_h - R_c}$$

Where K = calibration factor in terms of Btu per hr sq.ft millivolt

G_h = emissive power of hot surface (Btu/hr. sq ft)‡
G_c = emissive power of cold surface (Btu/hr sq ft)‡
R_h = response of instrument to hot plate (millivolts)
R_c = response of instrument to cold plate (millivolts)

Care should be taken to prevent drafts in the room while making the calibration, and it should be done as rapidly as possible to prevent the cold junctions of the radiometer thermopile changing in temperature.

Globe Thermometers. A globe thermometer is a hollow, blackened copper sphere (Fig. 5), with a thermometer or thermocouple at its center, used for measuring the combined effects of air temperature, radiation, and air velocity. If located in the sun, the globe temperature will reach a level somewhat above that of the air temperature, determined by the balance between the net heat received by radiation and heat lost by convection. Bedford and Warner[8] have reported the results of studies with a 6-in globe and give methods of calculating mean radiant temperature from the globe readings if the air temperature and velocity are known. In the California project, however, the greatest use for the instrument has been in the comparison of radiation under various types of shades, where air temperatures and velocities are very similar. The shade most effective in cutting off radiation will be indicated by a lower globe thermometer temperature.

The size of the globe influences the final globe temperature; increasing the globe size, up to a certain point, will increase its temperature under an environmental condition of high radiation intensity. In Fig. 9, globes of various sizes (2, 5, 6, and 10-in in diameter) are compared to a globe of zero diameter at air temperature since it theoretically would receive no heat radiation. The globes were stationed in bright sun near each other, at Davis, Calif. The curve indicates that the increase in temperature with diameter is low above a diameter of 6 in.

Periods of about 5 min for a 5-in globe and 15 min for a 10-in globe are necessary to reach the steady temperature state after being moved from the sun to a point in the shade. During these periods, air velocity and air temperature may vary a great deal. For those reasons, it is best to have globes permanently located at each location under consideration so that readings may be made as nearly simultaneously as possible.

Potentiometers. Most of the instruments so far described have made use of the thermoelectric effect—that is, an electromotive force is produced when two dissimilar metals are joined so that the junctions are at different temperatures. The electromotive force developed is approximately proportional to the temperature difference; for a copper-constantan couple this is about 0.0228 mv per deg F. depending somewhat on the temperature level. Measuring these relatively small potentials is usually accomplished with some type of potentiometer. A potentiometer also makes use of the comparison method—the unknown electromotive force is compared with the known potential of a standard cell through a calibrated resistor in a bridge circuit. In the usual form, a galvanometer indicates when balance or the "null point" has been obtained.

Questions regarding type of calibration, type of cold or reference junction and range will arise when the purchase of a potentiometer is being considered. Indicating potentiometers (manually balanced) ordinarily are calibrated to read both in temperature (if they have automatic cold junction compensation) and in electromotive force units. Recording potentiometers, on the other hand, are usually calibrated in one way only. It would seem desirable to *(Continued on page 304)*

† The Leslie Cube is a copper box with a 30-deg cone let into one side, into which the radiometer "looks" when being calibrated.

‡ $G = 0.173e\,(T/100)^4$, where e is emissivity and T is absolute temperature of surface.

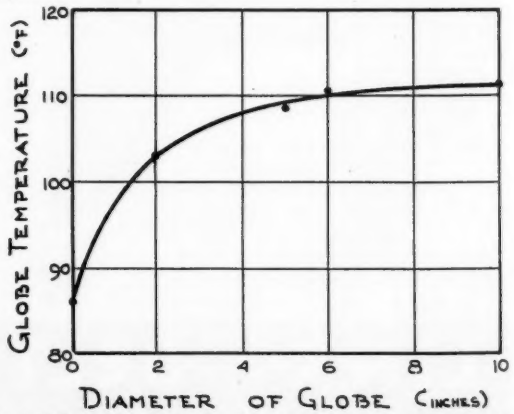

Fig. 9 Relation between globe thermometer diameter and temperature, as determined by average of several observations at Davis, Calif.

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Animal Shelter Research

(Continued from page 302)

have the instrument calibrated in millivolts so that the output of radiometers, thermopiles, heat flow meters, etc., can be determined.

A thermocouple consists of two junctions—the "hot" junction at the point where it is desired to measure the temperature, and the reference or "cold" junction. If a potentiometer is to be used only for indicating or recording temperatures through the use of thermocouples, it may be equipped with a device known as an automatic cold junction compensator, making an outside reference junction unnecessary. However, unless a bypass around the compensator is installed, the usefulness of the potentiometer thus equipped is limited when it is desired to read potential differences in terms of millivolts. Another undesirable feature of the compensated cold junction is the probability of errors in the indicated temperature if temperature gradients are set up in the instrument due to heat from the hands on the binding posts, radiation striking the binding posts at different intensities, etc. While the maintenance of a constant temperature reference either by means of an ice pot, a warm water or oil bath, or by burying the reference junction deep in the ground may be an inconvenience, it is believed that for a general-purpose instrument one of those methods will be found more desirable in the long run than the automatic cold junction compensator.

The range of the potentiometer should be great enough to measure the highest electromotive force that will be encountered. On the other hand, the full scale movement per millivolt should be as great as possible. Of the instruments discussed in this paper, the flat plate radiometer has the highest output, running as high as 15 millivolts on a hot bright day. A heat-flow meter with a calibration factor of 20 Btu per hr sq ft mv may have an output of 3 millivolts when held against a hog in an environment of 40 F. If the calibration factor is smaller, the output will be relatively higher for a given rate of heat flow. A copper-constantan thermocouple using an ice pot reference at 32 F will generate an electromotive force of 2.96 mv when used to measure a temperature of 160 F, the highest that will usually be encountered in animal shelter research. The range of most indicating potentiometers will easily include all these levels but recording instruments vary in range.

Where most of the readings will be relatively low, an occasional high reading may be recorded by connecting an outside potential in opposition to the electromotive force to be measured, so that only the difference is recorded. An indicating potentiometer provides an excellent source for the opposing potential because the value desired can be obtained by merely setting the slide wire to the point necessary to bring the electromotive force being measured into the range of the recorder. With certain types of recording potentiometers, voltage dividers also offer possibilities of quickly changing the range for occasional readings.

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Unloads Hay by machine eliminating hand labor

This novel machine *(above)*, powered by a 1½-hp motor, operates a conveyer belt on the bottom of the wagon, unloading the hay into the blower. Mr. Byron Harris, inventor, uses Marfak lubricant on this machine because it stays on the job longer.

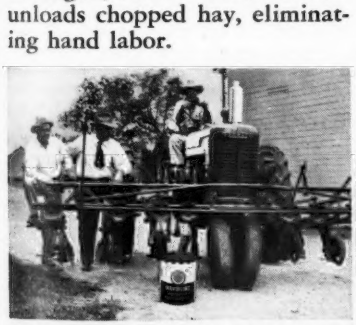
Marfak lubricant improves the performance of this hay chopper *(at right)* for it sticks to bearings better, won't wash off, melt down and drip off, dry out or cake up. That's why Mr. Harris, like keen farmers the country over, uses it. Texaco Man, F. G. McKelvey, watches operation.

Farmer Invents Mechanical Unloader for Chopped Hay

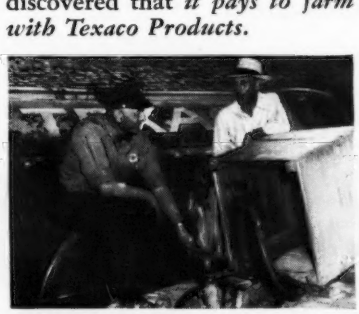
From odd parts of a number of old machines — the transmission of a Model A Ford and a 1½-hp motor — Mr. Byron Harris, ingenious farmer of near Ravenna, Michigan, built a machine that unloads chopped hay, eliminating hand labor.

The machine operates a conveyer belt at the bottom of the wagon, automatically dumping the hay into the blower which carries the hay up into the loft.

With this machine, a hay chopper and a blower, Mr. Harris saves time, labor and money in his haying operation. He has also discovered that *it pays to farm with Texaco Products.*



In the South where motor oil has to stand up under high temperatures, Havoline is the choice of leading farmers. Typical example is the cotton farm of Mr. J. Stoneham, near Navasota, Tex. Picture shows Mr. Stoneham *(left)* with Texaco Man, L. Millican, and Fred Luce at wheel.



Dealing with your Texaco Man is a friendly business. Mr. Clark Mauk *(shown at right)*, prominent apple grower of Wenatchee, Washington, is getting a tankful of Fire-Chief, the gasoline with superior *"Fire-Power,"* from Texaco Man, T. J. Stockstill.

Drives Car 110,000 Miles and Operates Tractor 6 Years—Using Havoline Motor Oil—Without an Overhaul

Mr. C. E. Oldfield, farmer of Manhattan, Kansas, feels that farmers everywhere ought to know the results he has had with Havoline, the motor oil that *cleans as it lubricates.* He reported that he drove his car 110,000 miles and operated his tractor for 6 years without touching either engine. He is shown below telling his story to Mr. O. C. Schryer, Texaco Man, of Manhattan.

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NEWS SECTION

A.S.A.E. Meetings Calendar

June 20 to 23 — ANNUAL MEETING, Michigan State College, East Lansing

September 7 to 9 — NORTH ATLANTIC SECTION, Pennsylvania State College, State College

October 6 to 8 — PACIFIC NORTHWEST SECTION, Harrison Hot Springs Hotel, Harrison Hot Springs, B. C.

December 19 to 21 — WINTER MEETING, Stevens Hotel, Chicago, Ill.

Guy Halsey Chairman of Virginia Section

GUY W. HALSEY is the new chairman of the Virginia Section of the American Society of Agricultural Engineers. Mr. Halsey is a territory supervisor of the J. I. Case Co., and was elected to the office of Virginia Section chairman at the Section's annual meeting at Roanoke on April 15 and 16. He succeeds G. D. Kite. At this meeting three new vice-chairmen of the Section were also elected: T. W. Edminster, research agricultural engineer, U. S. Soil Conservation Service, and E. T. Swink and J. A. Waller, Jr., both extension agricultural engineers, Virginia Polytechnic Institute. J. E. Collins, also an extension agricultural engineer of VPI, was re-elected as secretary-treasurer of the Section. The new Nominating Committee includes U. F. Earp, L. M. Miller, and J. W. Sjogren.

A total of 83 persons attended the meeting, including 60 ASAE members and guests and 23 members of the Student Branch of the Society at VPI.

The main part of the program of the meeting centered around the four major fields of agricultural engineering. One of the principal speakers was ASAE President Arthur J. Schwantes, who discussed Society activities from the national standpoint.

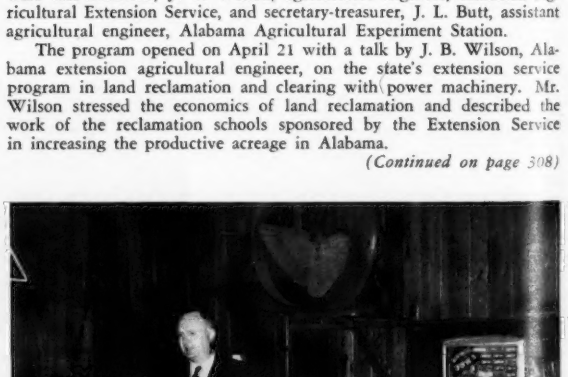
The Section dinner was held on the evening of April 15 at which the principal speaker was Arthur W. Turner, assistant chief, USDA Bureau of Plant Industry, Soils, and Agricultural Engineering, who addressed the group on the subject of agricultural engineering research.

Womack to Head Alabama Section

AT ITS spring meeting attended by 42 members and guests, on April 21 and 22 at Gulf Shores, Alabama, the Alabama Section of the American Society of Agricultural Engineers elected William A. Womack, owner and operator of Rocky Creek Farms, Ashford, as the new chairman of the Section succeeding E. C. Easter. Other officers elected were vice-chairman, J. B. Wilson, agricultural engineer, Alabama Agricultural Extension Service, and secretary-treasurer, J. L. Butt, assistant agricultural engineer, Alabama Agricultural Experiment Station.

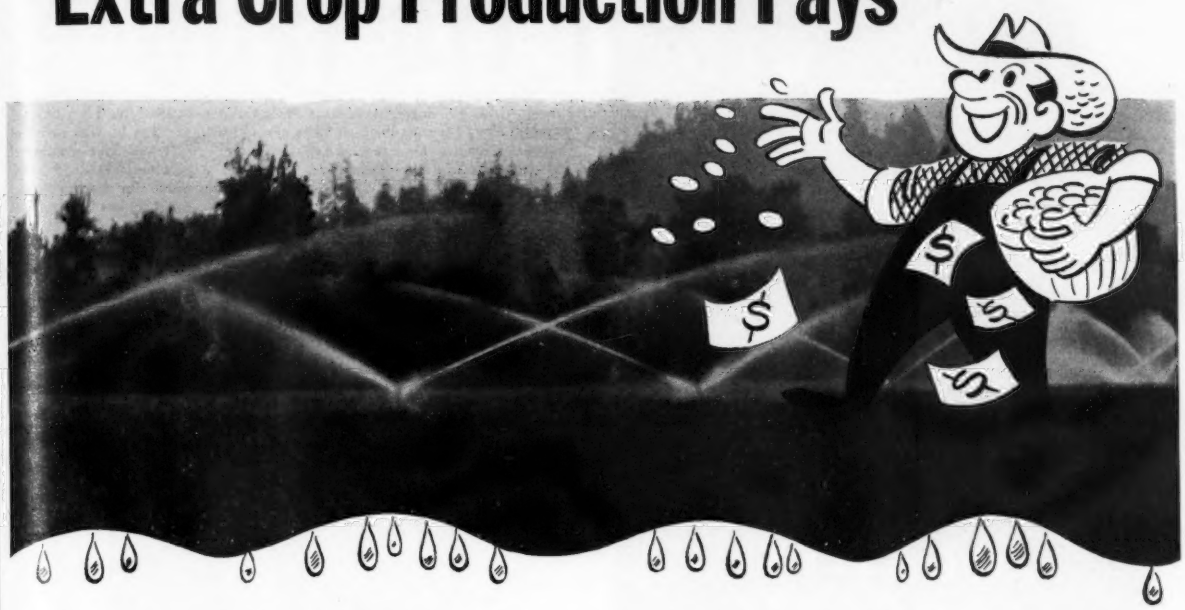
The program opened on April 21 with a talk by J. B. Wilson, Alabama extension agricultural engineer, on the state's extension service program in land reclamation and clearing with power machinery. Mr. Wilson stressed the economics of land reclamation and described the work of the reclamation schools sponsored by the Extension Service in increasing the productive acreage in Alabama.

(Continued on page 308)



This picture shows Henry Sweet, director, Alabama State Docks and Terminals, speaking at the recent meeting of the Alabama Section, ASAE, at Gulf Shores, Ala. Those in the picture are (left to right) W. A. Womack, newly-elected chairman, Alabama Section; Mr. Sweet; E. C. Easter, retiring chairman, Alabama Section, and R. F. Weston, Hollingsworth and Whitney Paper Co., who also addressed the group

Extra Crop Production Pays



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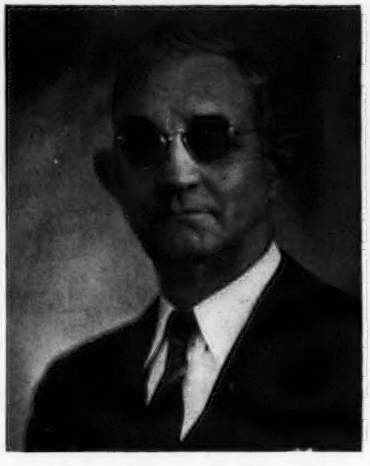
Harry M. Bainer Passes Away

HARRY M. BAINER, general agricultural agent for the Santa Fe Railway at Amarillo, Texas, passed away Saturday, April 23, in the Grand Central Station, New York City, while en route home from a meeting of the American Railway Development Association held at Old Point Comfort, Va.

Mr. Bainer was born at Ancram, New York, August 16, 1880. He received his BS degree at Kansas State College in 1900, and his MS degree at Iowa State College in 1905. From 1903 to 1906 he was assistant in agricultural engineering at Iowa State College. He was next employed as professor of farm mechanics at Colorado Agricultural College, from 1906 until 1910. Then he started work for the Santa Fe as agricultural agent July 1, 1910, at Amarillo. From 1916 to 1918 he was agricultural and industrial agent at Topeka, Kans. In 1918 he became director of



HARRY M. BAINER, 1880-1949

the Southwestern Wheat Improvement Association, Kansas City, serving in that capacity until 1928 when he was made farm manager of the Missouri Bank and Trust Company at Kansas City. In 1935, Mr. Bainer returned to the Santa Fe as general agricultural agent, at Amarillo, which post he held until his death.

Mr. Bainer was widely known for his agricultural activities, and was a charter and life member of the American Society of Agricultural Engineers, was twice elected an honorary member of the Texas Future Farmers of America, was a member of the National Farm Chemurgic Council, National Reclamation Association, American Railway Development Association, Association of Texas Agricultural Workers, and the Texas Farm Bureau Federation.

Survivors are his widow, two sons, Robert, of Ft. Collins, Colo., and Roy, of Davis, Calif., a daughter, Mrs. R. J. Johnson, of Schenectady, N. Y., and a brother, Fred, of Whittier, Calif.

NEWS SECTION *(Continued from page 306)*

The agricultural engineer of the Greenville (Ala.) Electric Cooperative, Mr. Roberts, discussed the work of the REA cooperatives in the state and the educational program being carried on to teach the proper installation, use, and maintenance techniques for electrical facilities. Hayden Rogers, plant breeder at the Alabama Agricultural Experiment Station, discussed hybrid seed corn production in Alabama, showed how hybrids are produced, and stressed the need for proper machinery and storage facilities for safe handling of the more expensive hybrid seed. Otto Brown, superintendent of the Gulf Coast substation of the Alabama station presented the results of their irrigation experiments, which showed increased yields due to supplemental irrigation in most of the crops even under the high rainfall conditions of the Gulf Coast region. The latter part of the afternoon session was devoted to a business session, at which were elected the new officers named above. Various committees were appointed by the new chairman of the Section and it was decided to hold the fall meeting on the campus of the Alabama Polytechnic Institute in the new agricultural engineering annex scheduled to be completed early this summer.

Guest speakers at the Section dinner held during the evening of April 21 included Henry Sweet, director, Alabama State Docks and Terminals, and R. F. Weston, Hollingsworth and Whitney Paper Co., both of Mobile. At the conclusion of their talks a motion picture film was shown presenting the experimental activities of the agricultural engineering department of the Alabama station.

(News continued on page 310)

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NEWS SECTION *(Continued from page 308)*

J. C. Cahill Elected by Michigan Section

J. C. CAHILL was elected the new chairman of the Michigan Area Section of the American Society of Agricultural Engineers at the Section meeting held at Battle Creek, April 30. Mr. Cahill is farm service coordinator of the Detroit Edison Company, and succeeds Dan M. Guy, agricultural engineer, Ethyl Corp., as Section chairman.

At the same meeting three new vice-chairmen of the Section were elected as follows: J. S. Boyd, assistant professor of agricultural engineering, Michigan State College; Chris Nyberg, chief engineer, Battle Creek Works, The Oliver Corp., and C. B. Richey, project engineer, Dearborn Motors Corp. F. W. Peikert was re-elected secretary-treasurer, and the Section's new nominating committee consists of A. W. Farrall (chairman), H. J. Gallagher, and D. A. Milligan.

The technical program for the meeting included three papers, one on the use of liquid in tractor tires by Jack R. Schramm, graduate student in agricultural engineering, Michigan State College; another by Ralph W. Sohl, Goodyear Tire and Rubber Co., on rubber tracks for farm and industrial tractors, and a third by J. W. Shields, United States Rubber Co., on testing farm tractor tires at the USDA Tillage Machinery Laboratory at Auburn, Ala., which included motion pictures and slides.

Inasmuch as the Michigan Area Section, together with Michigan State College, is to be host of the 1949 ASAE Annual Meeting at East Lansing, considerable discussion was devoted to arrangements for the East Lansing meeting.

Greeks Do Well with Farm Machinery

By M. A. Sharp

MEMBER A.S.A.E.

PREVIOUS to March, 1948, Greece had received considerable farm machinery from UNRRA, U. S. Army Surplus, American Mission for Aid to Greece, and other sources. There was no organization to teach farmers how to adjust and repair this machinery, and consequently it was not being operated efficiently.

There was a definite need for training schools all over the nation, but there were no trained teachers. The first step needed was to train a group of men to organize and conduct farmers' short courses and use the most effective teaching methods. The writer was employed by AMAG and sent there to train teachers and set up an organization to carry out a broad training program. There were a few men who had been operating tractors and machinery for the government and were excellent mechanics. All they needed was training in organization and methods. Three groups of men were selected on the basis of their experience in repair shops and field operations. Training schools were held at Athens, Salonika, and Volos. Out of 75 men enrolled about thirty were considered qualified to organize and conduct 10-day short courses in the operation, adjustment, and repair of farm machinery.

Mr. John Sinis, director of the farm machinery testing laboratory in the Ministry of Agriculture was selected to organize and direct the training program. He is exceptionally well qualified and the results have been very good. During September, October, and November (1948) about 50 short courses were held and over 100 men were trained. No report has been received regarding the schools held during the winter.

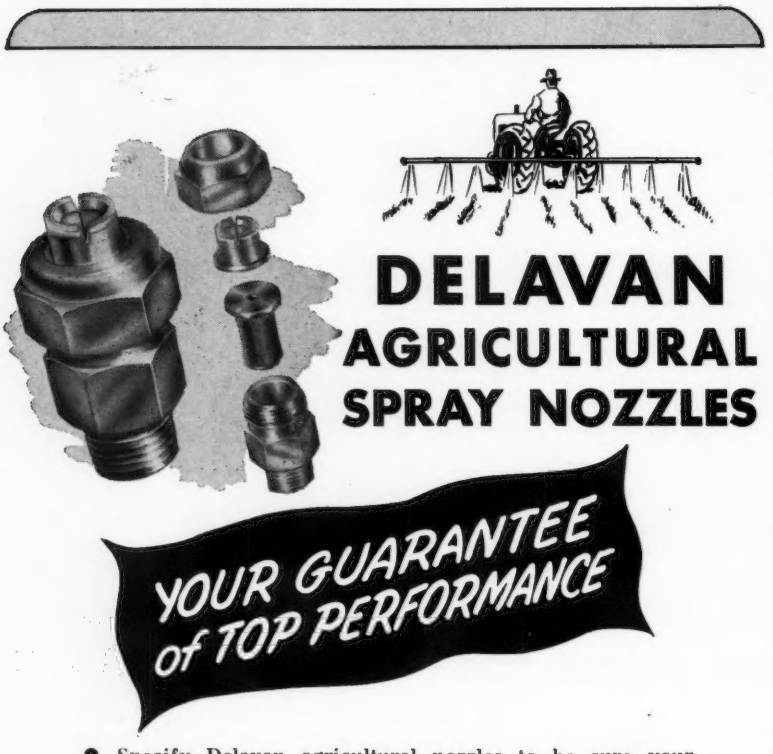
It was interesting to learn that most of the men selected for training knew as much as we do about our machinery. They analyze the operation and functions of each part carefully, and have a good understanding of engineering principles. They work hard and are eager to learn. Classes were held 8 to 9 hours every day, but they always wanted to stay longer. The Greeks are good mechanics, appreciate good machinery, and take good care of it.

M. A. SHARP is head of the agricultural engineering department, University of Tennessee. In the spring of 1948, he was sent to Greece by the U. S. Department of Agriculture to help organize the training of Greeks in the use and maintenance of farm machinery.

Farm Work Functions

(Continued from page 269)

sensitive than the human eye, ear, or sense of touch; gages more accurate than human judgment; jigs, fixtures, and machines which will turn out work more uniform than can be reproduced by manual skill; governors, relays, and other actuators more reliable than human memory and discretion; and methods to match their mechanisms. We like to think of engineering as technically applicable to all the physical functions of agriculture; as economically applicable to all of its major production operations; and as a potential aid to much of its essentially human supervisory work, including planning, initialing, directing, and controlling the progress of operations. In these terms there is no visible end to opportunity to apply engineering to the equipment, operations, and service of agriculture.



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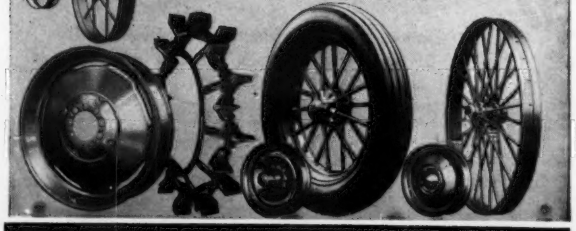

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Applicants for Membership

The following is a list of recent applicants for membership in the American Society of Agricultural Engineers. Members of the Society are urged to send information relative to applicants for consideration of the Council prior to election.

Autry, J. W.—Associate professor of agricultural engineering, Tarleton State College (Mail) Box 655, Tarleton Station, Tex.

Bales, G. A.—Farm representative, Texas Electric Service Co., Electric Bldg., Fort Worth, Tex.

Baranao, Teofilo V.—Director del Instituto de Mecanica Agricola, Facultad de Agronomia y Veterinaria, Av. San Martin 4453, Buenos Aires, Argentina.

Bartlett, Howard O.—Assistant agricultural engineer, Maine Agricultural Experiment Station, Orono, Maine.

Berry, J. H.—Assistant in charge of new design, John Deere Ottumwa Wks., Ottumwa, Iowa. Mail) 220 Gara.

Bywater, J. E.—Chief implement designer, Imperial Foundry Co., Princes Drive, Leamington SPA, Warwickshire, England.

Christopher, R. W.—District supervisor, Southern Ford Tractor & Equipment Co., (Mail) Box 114, Mangham, La.

Dickison, William—Technical representative, H. D. Hudson Mfg. Co., 589 E. Illinois St., Chicago 11, Ill.

Dorsey, E. S.—Manager, Dorsey's Stock Farm, R.R. No. 4, Box 101, Opelika, Ala.

Greer, George R.—Salesman, Dickerson Machine Co., 423 W. First, Spokane, Wash.

Hicks, Jesse L.—R. R. No. 4, Paris, Tenn.

Jessup, Joseph L.—Laboratory test assistant, Harry Ferguson, Inc. (Mail) 2843 Parker, Dearborn, Mich.

Larson, Lawrence W.—Box 31, Sweet Hall, Moscow, Idaho.

Lawson, Garland L.—P. O. Box 1135, Stillwater, Okla.

Lorance, C. M.—Agricultural engineer, Duck River Electric Membership Corp., Shelbyville, Tenn.

Love, Mahlon L.—Engineering dept., John Deere Harvester Works, East Moline, Ill.

Magee, J. M.—Agricultural engineer, Soil Conservation Service, USDA, (Mail) Box 815, Lubbock, Tex.

McMillan, Arthur W.—Rural representative, Wheeling Electric Co., Wheeling, W. Va. (Mail) 401 S. Broadway St.

Moore, David S.—203 Mall St., Corvallis, Ore.

Mount, Paul H.—109 North 4th St., Reading, Pa.

Nordstrom, Walter A.—Engineering checker, Harry Ferguson, Inc. (Mail) 270 Channing, Ferndale 20, Mich.

Osborne, Robert F.—Service engineer, Minneapolis-Moline Co., (Mail) R. R. No. 3, Peoria, Ill.

Peterson, Clarence W.—Agricultural engineer, Lake Region Cooperative Electrical Assn., Pelican Rapids, Minn.

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TRANSFER OF GRADE

Belt, V. C.—President and general manager, The Belt Corp., Orient, Ohio (Junior Member to Member).

New Federal and State Bulletins

Frozen Food Locker Plants in Georgia, by H. D. White, W. M. Hurst, and W. E. Garner. University of Georgia (Athens) and U. S. Department of Agriculture. A survey of operations, layout and equipment, representative of those found in the state. This is a preliminary report, to be followed by further research and more specific recommendations.